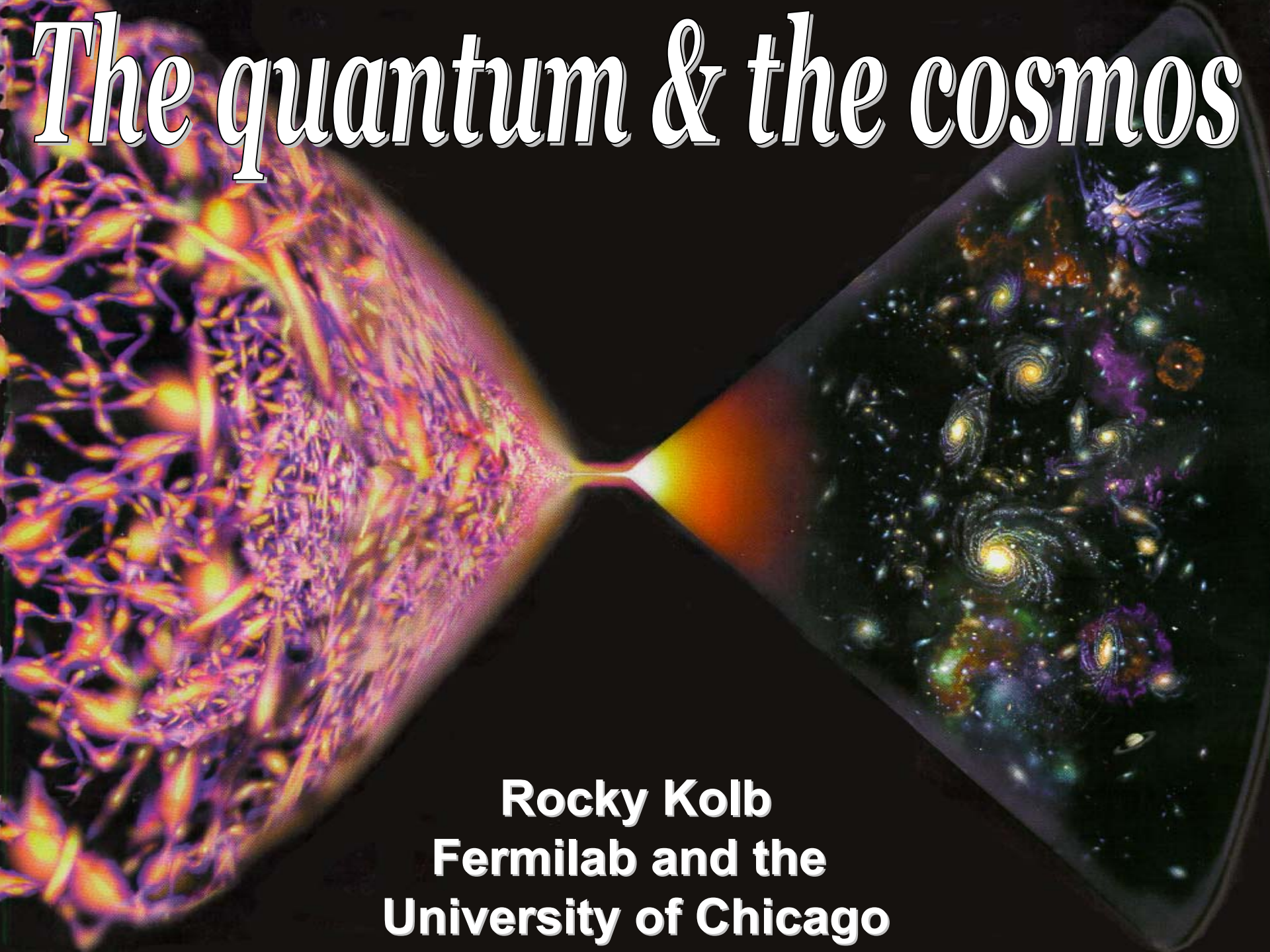
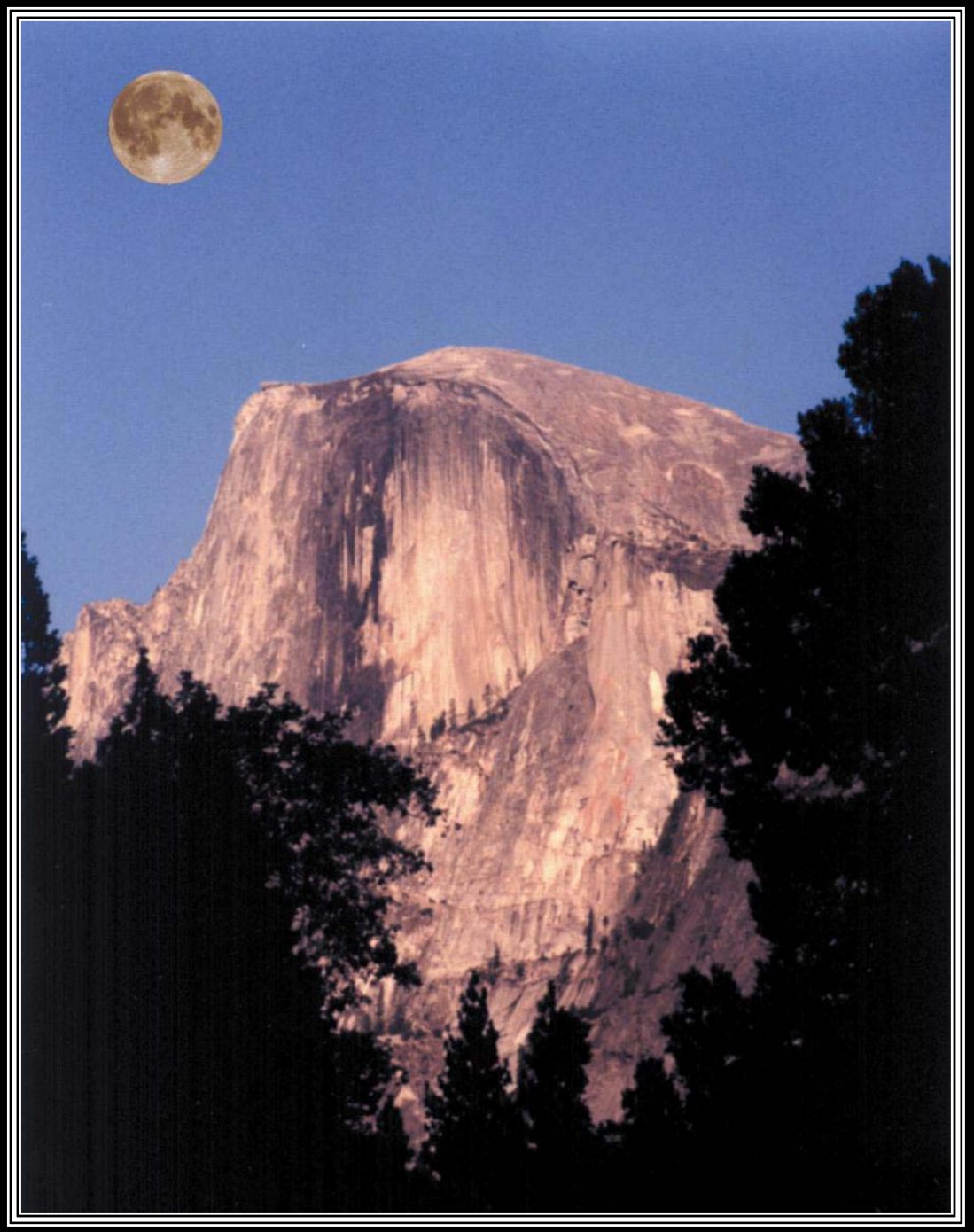
The quantum & the cosmos

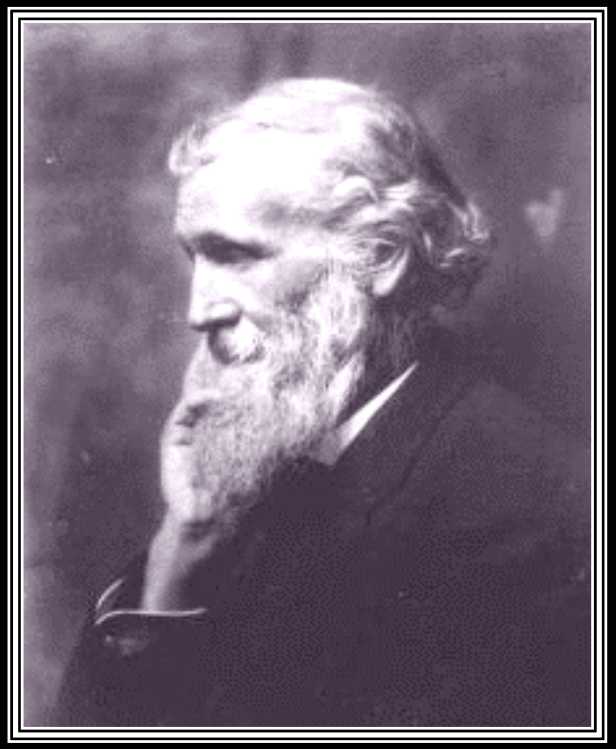


Rocky Kolb
Fermilab and the
University of Chicago



When one tugs at a single thing in nature, he finds it hitched to the rest of the universe.

– John Muir

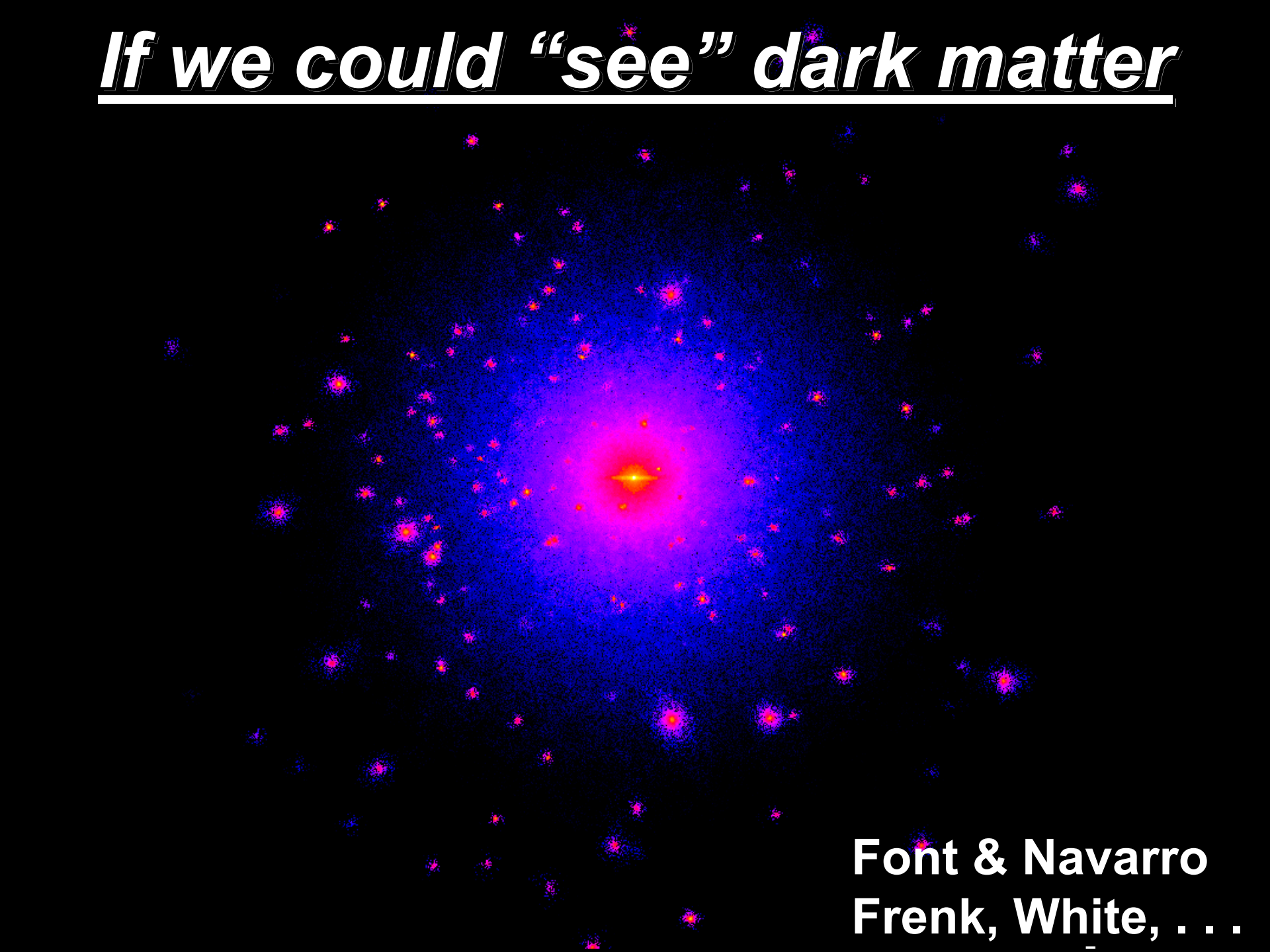


Visible matter

Galaxies: the visible universe

NGC253 in Sculptor

If we could "see" dark matter



Font & Navarro
Frenk, White, . . .

Dark matter

Dark matter: the invisible universe

(50 times more dark than visible matter)

the weight of space

Cosmological constant

(dark energy)

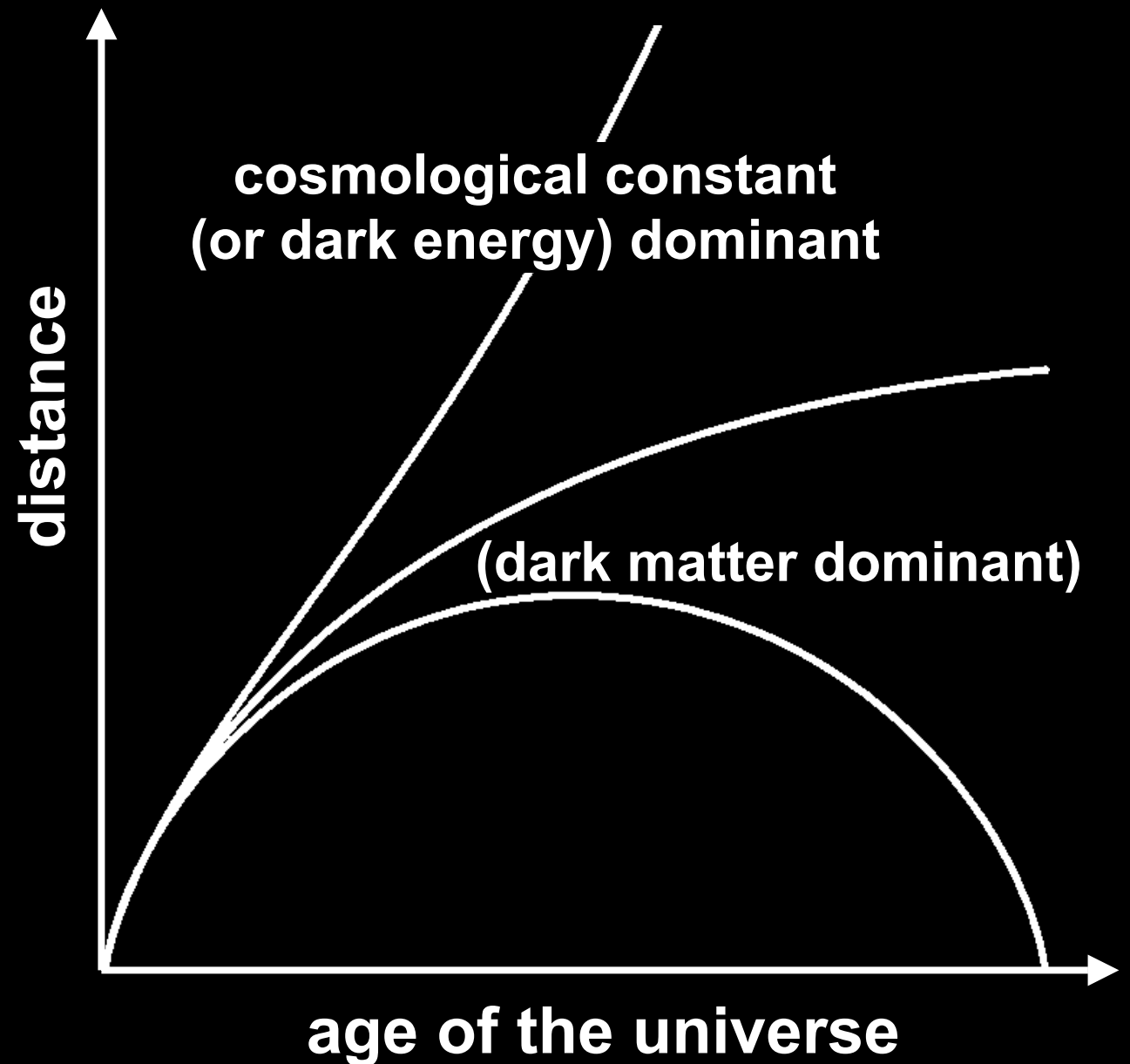
1917 Einstein proposes cosmological constant

1929 Hubble discovers Expansion of the universe

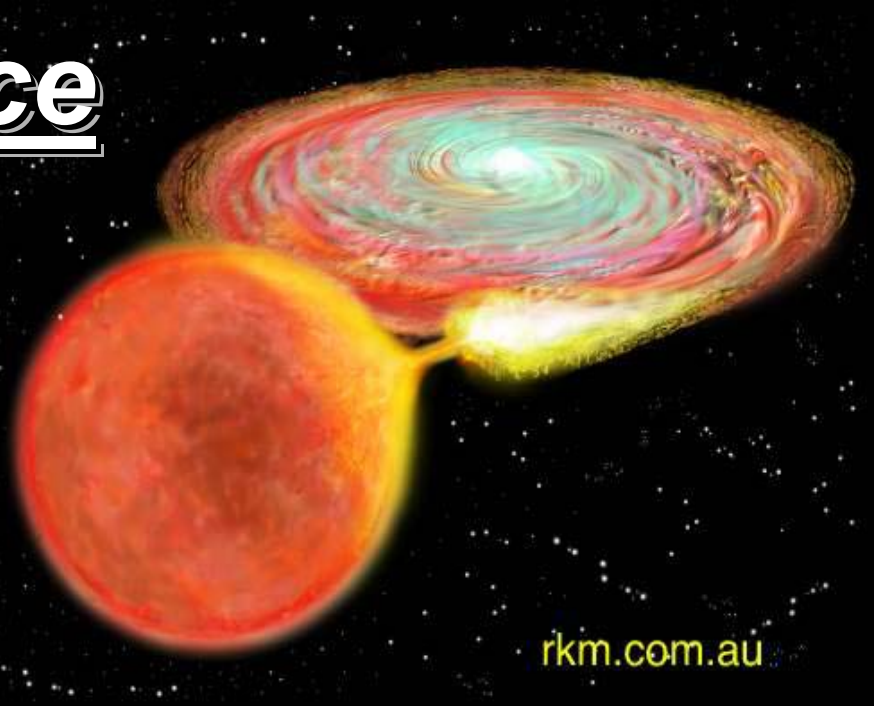
1934 Einstein calls it "my biggest blunder"

1998 Astronomers find evidence for it

Cosmological constant (dark energy)

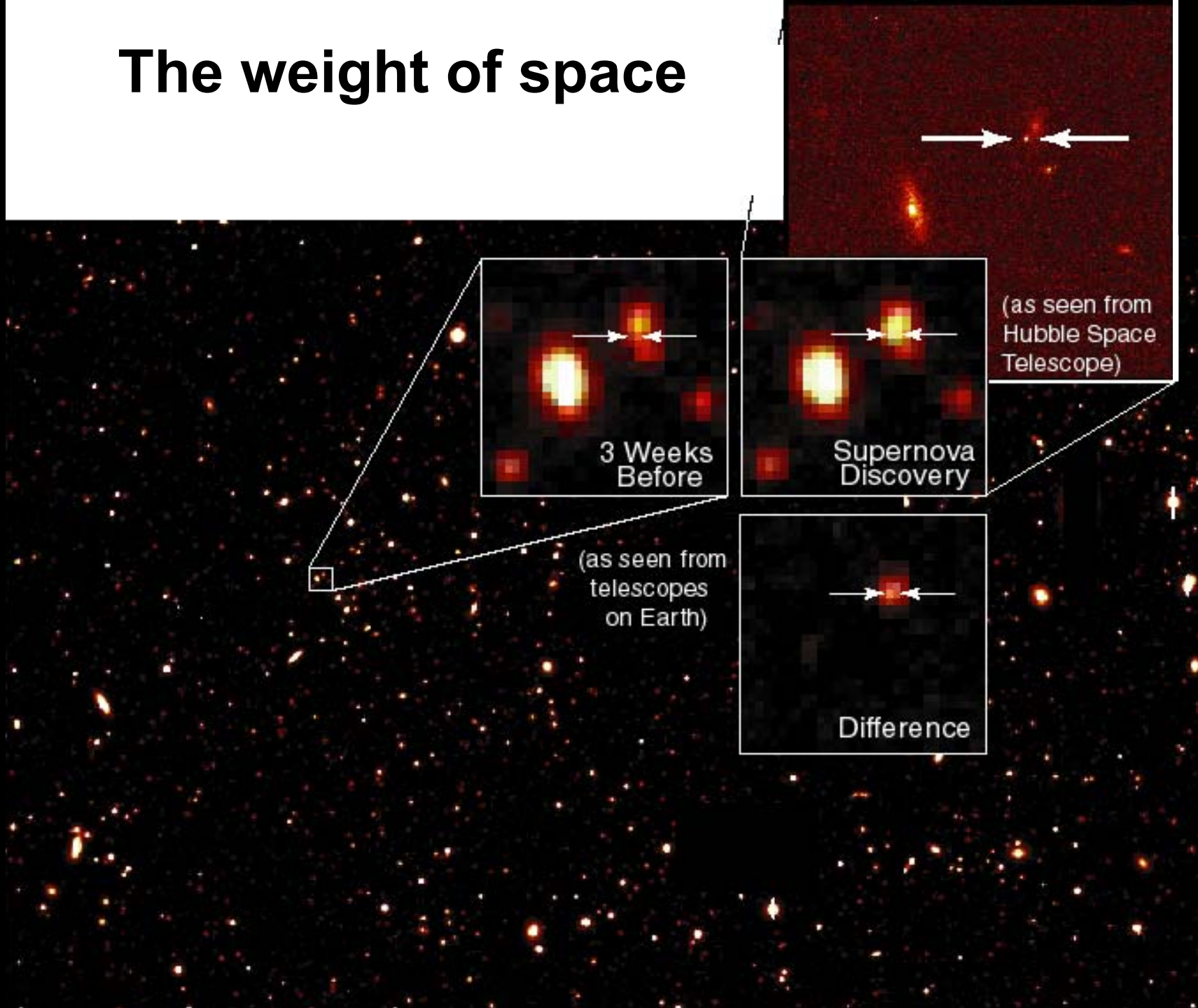


The weight of space



Type Ia supernovae

The weight of space



Supernova Cosmology Project (Perlmutter et al.)

Cosmological constant (dark energy)

Mass density of space: $10^{-30}\ \mathrm{g\ cm^{-3}}$

The unbearable lightness of nothing!

Cosmo-illogical constant?

Think about nothing (the vacuum)

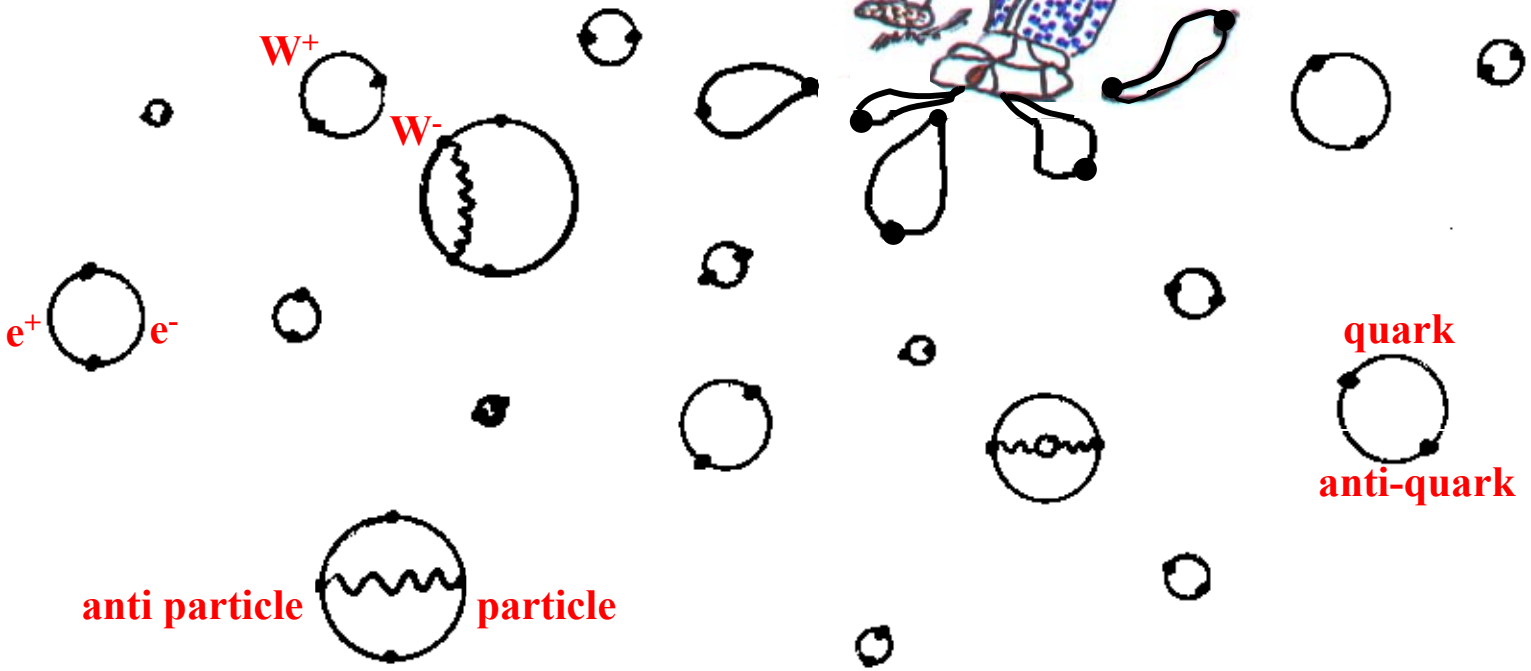
MUCH ADO ABOUT NOTHING:

NOTHING is something!

NOTHING has energy!

NOTHING matters!

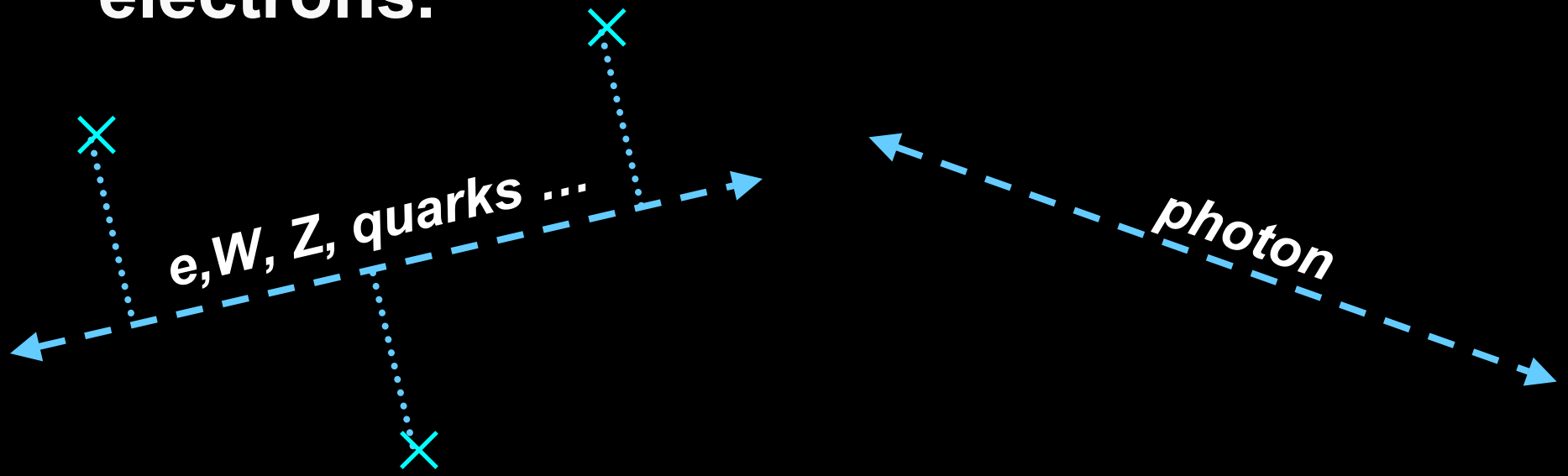
Quantum Uncertainty and the Vacuum



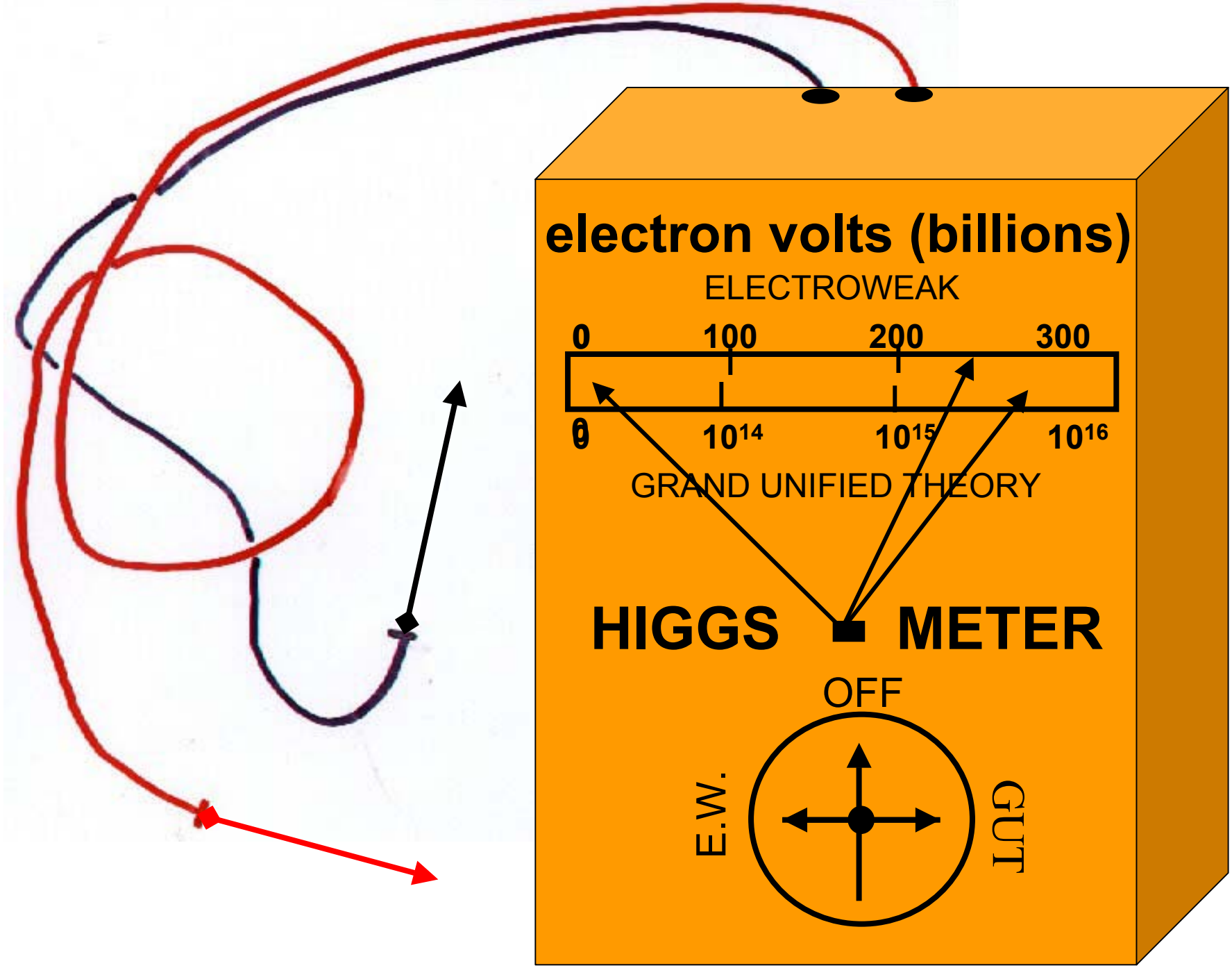
Nothing is Something!

The Higgs potential

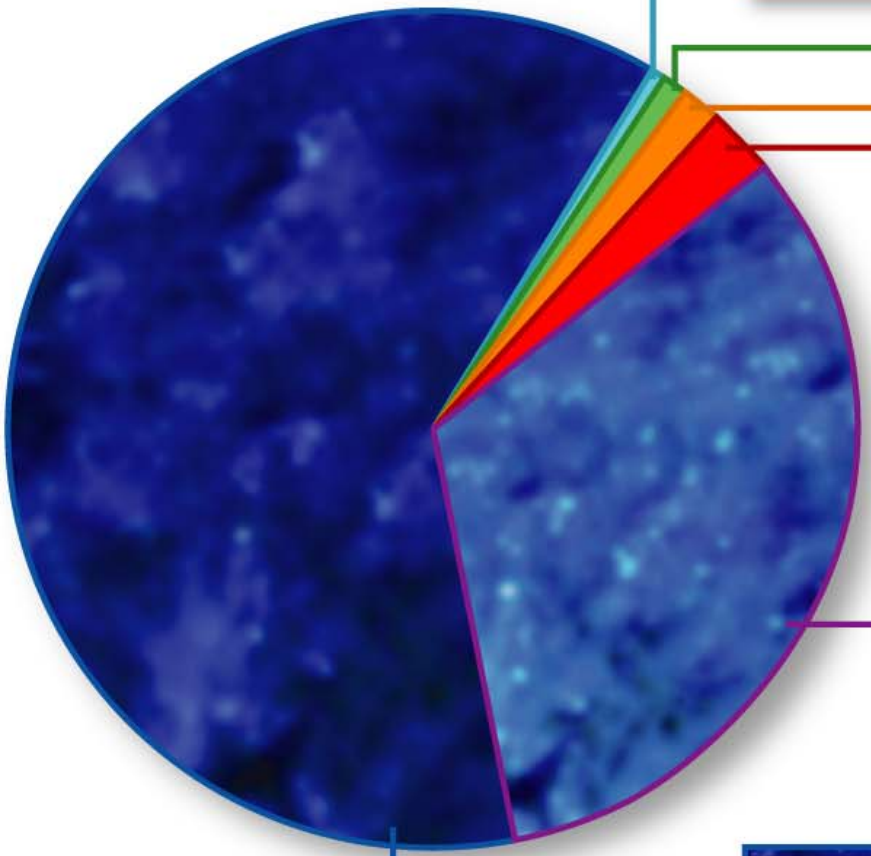
- The vacuum has a “Higgs potential”
- Interaction with the Higgs field potential gives mass to particles like quarks and electrons.



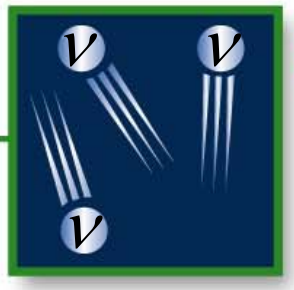
Nothing has energy:


electron volts (billions)
ELECTROWEAK
0
100
200
300
0
10^{14}
10^{15}
10^{16}
GRAND UNIFIED THEORY
HIGGS METER
OFF
E.W.
GUT

Cosmic Pie

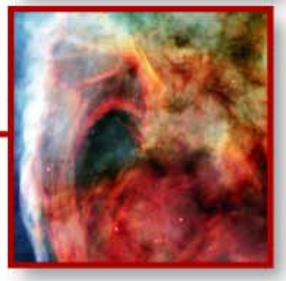


Heavy Elements:
0.03%

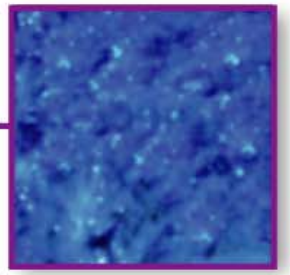


Neutrinos:
0.47%

Stars:
0.5%



Free H & He:
4%

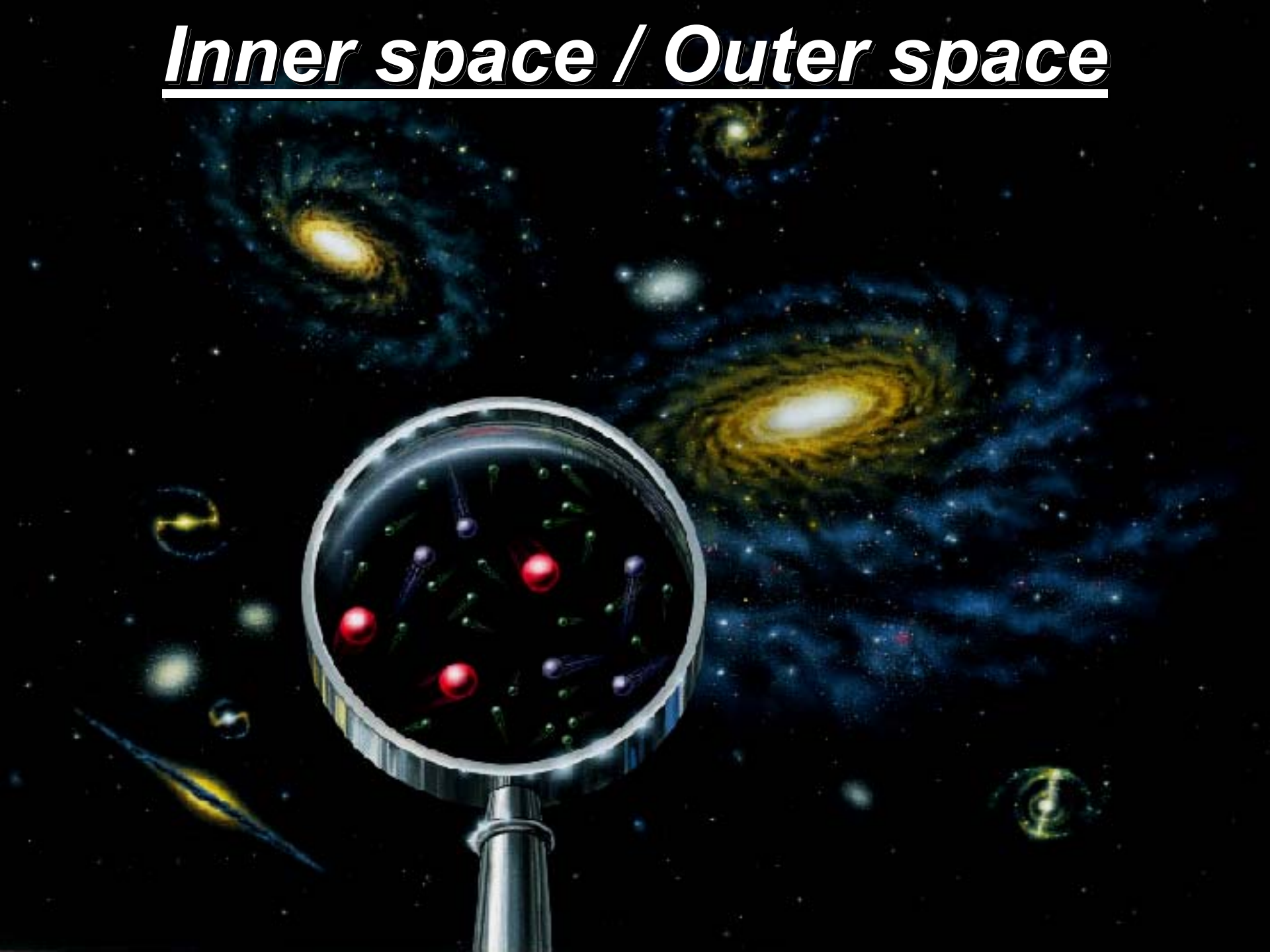


Dark Matter:
25%

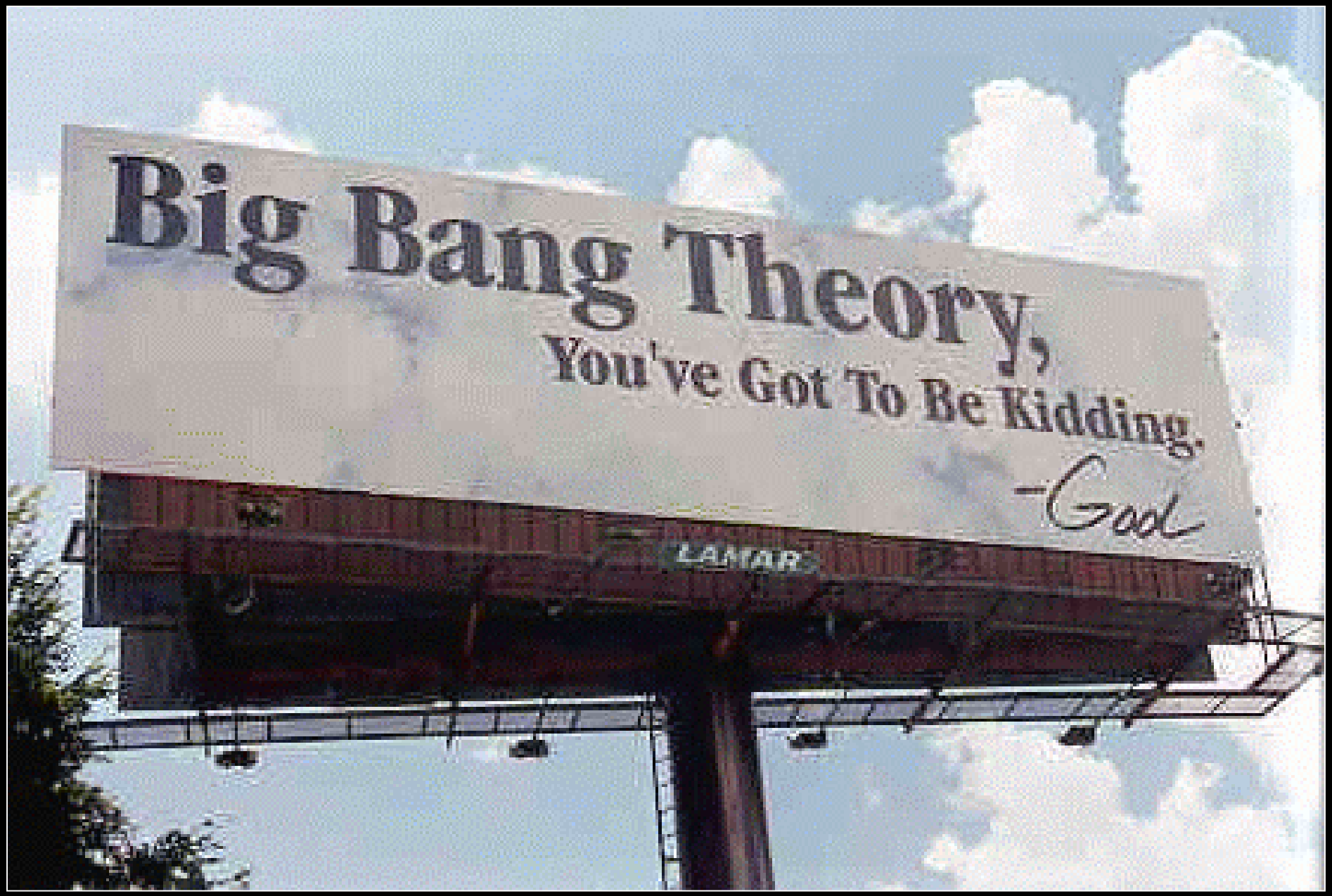
Dark Energy:
70%

Nothing Matters

Inner space / Outer space

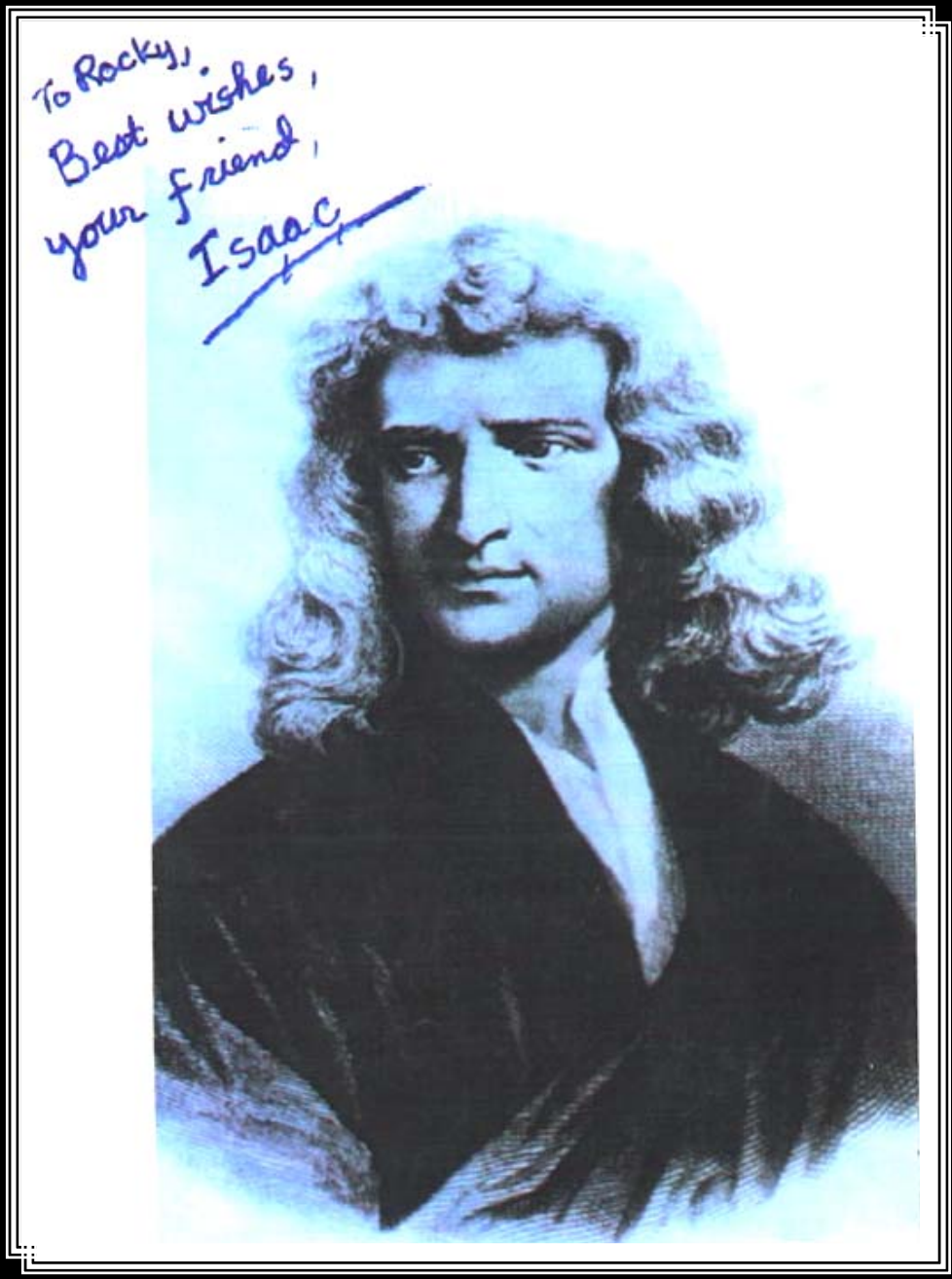


Dark matter from the big bang



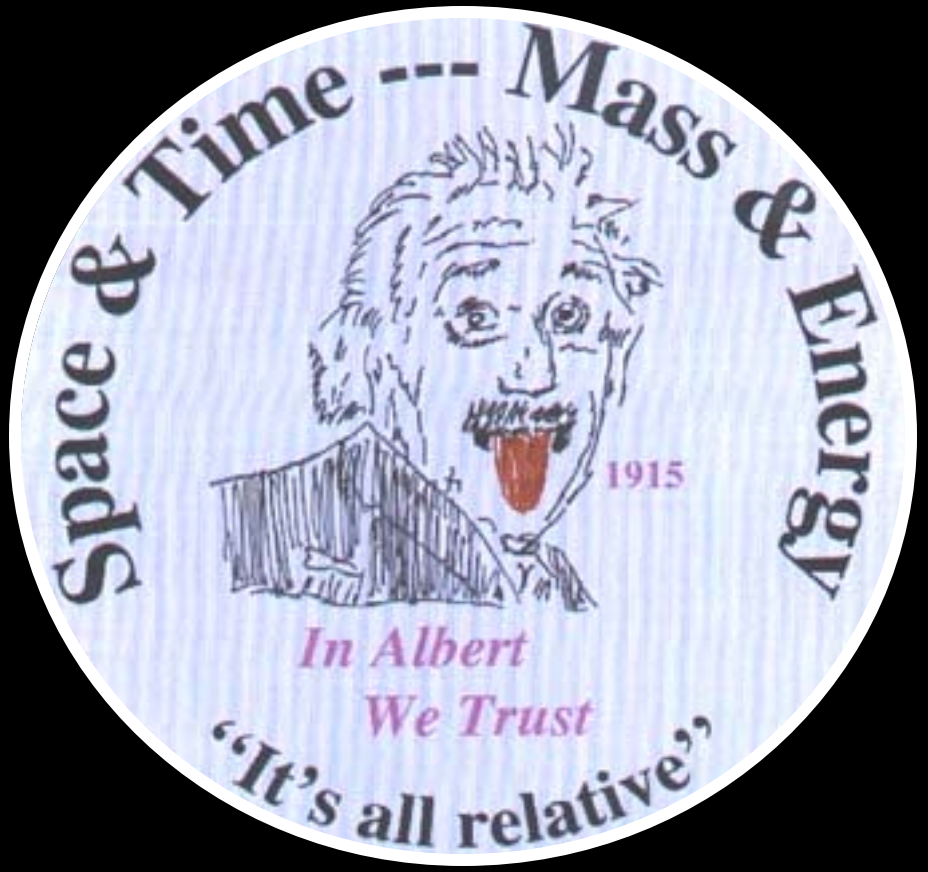
Absolute space,
in its own nature,
without relation
to anything external,
remains always similar
and immovable.

Isaac Newton
1686
Principia



Space and time
are related.

Albert Einstein
1905



Space is dynamical
(curved, warped, bent,
etc.).

Albert Einstein
1915

Space expands.

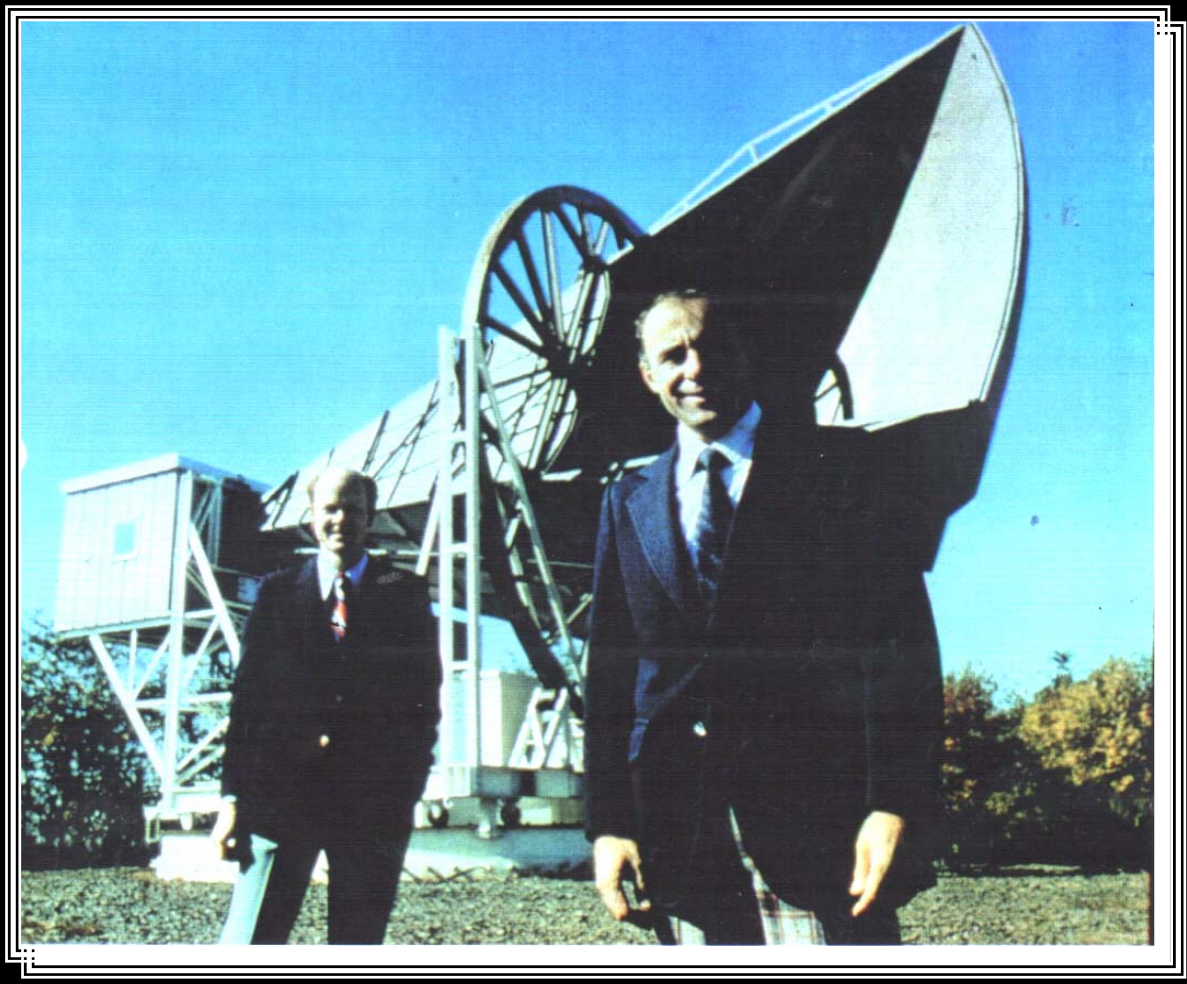
Edwin Hubble
1929

The University of Chicago

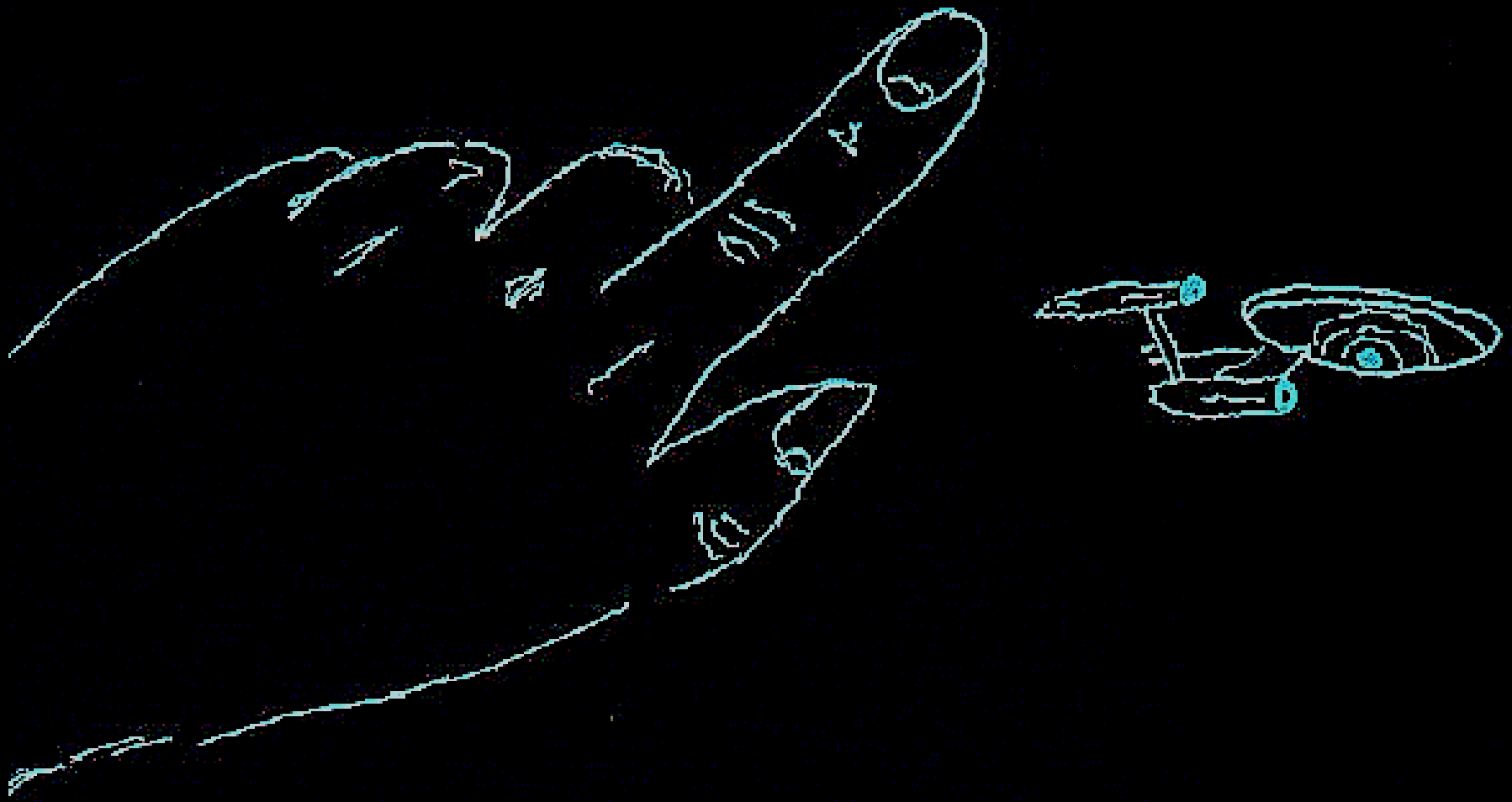
1909 National Champions

The universe
is radiant.

Arno Penzias
Robert Wilson
1965



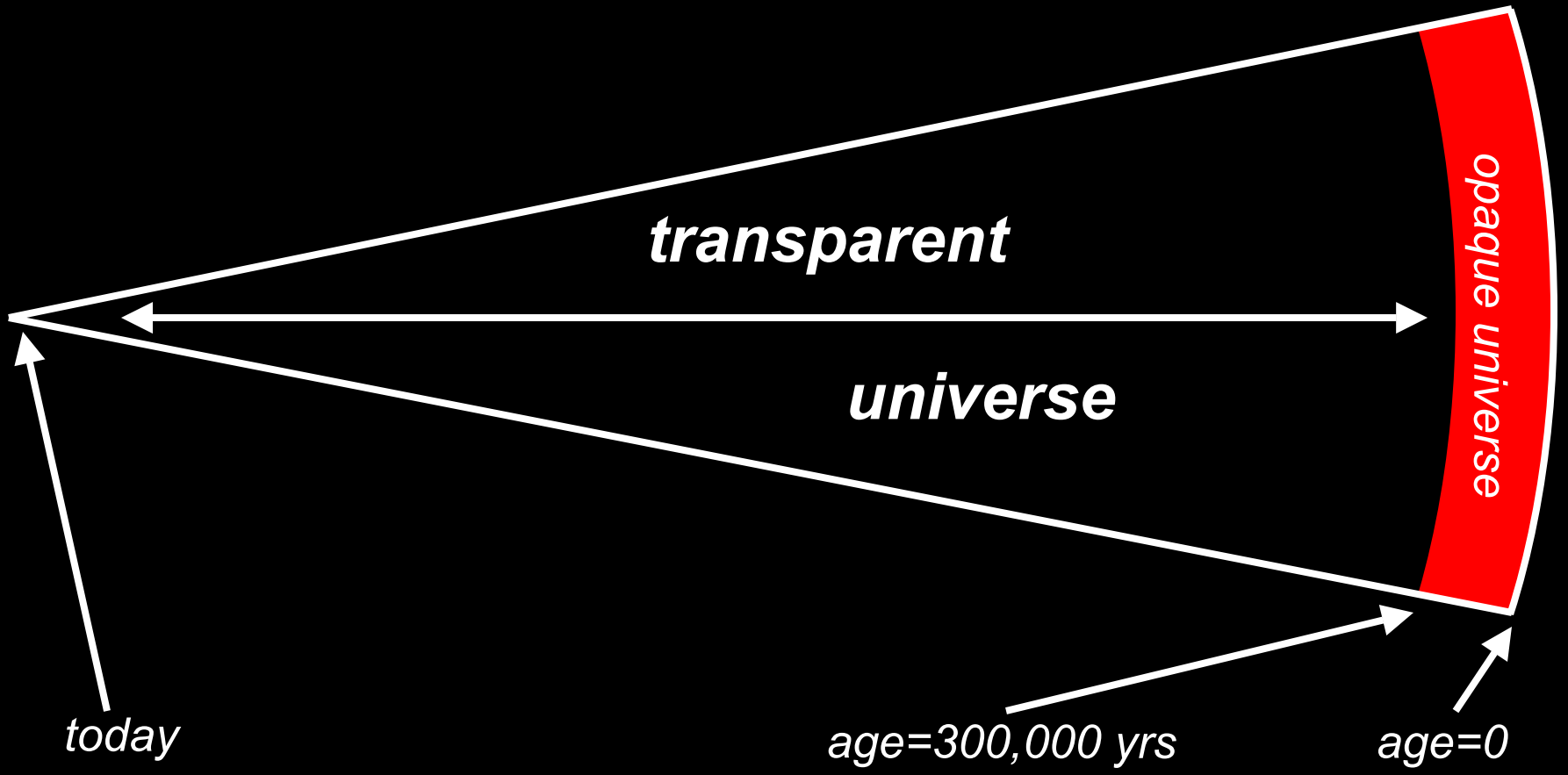
Cosmic background radiation

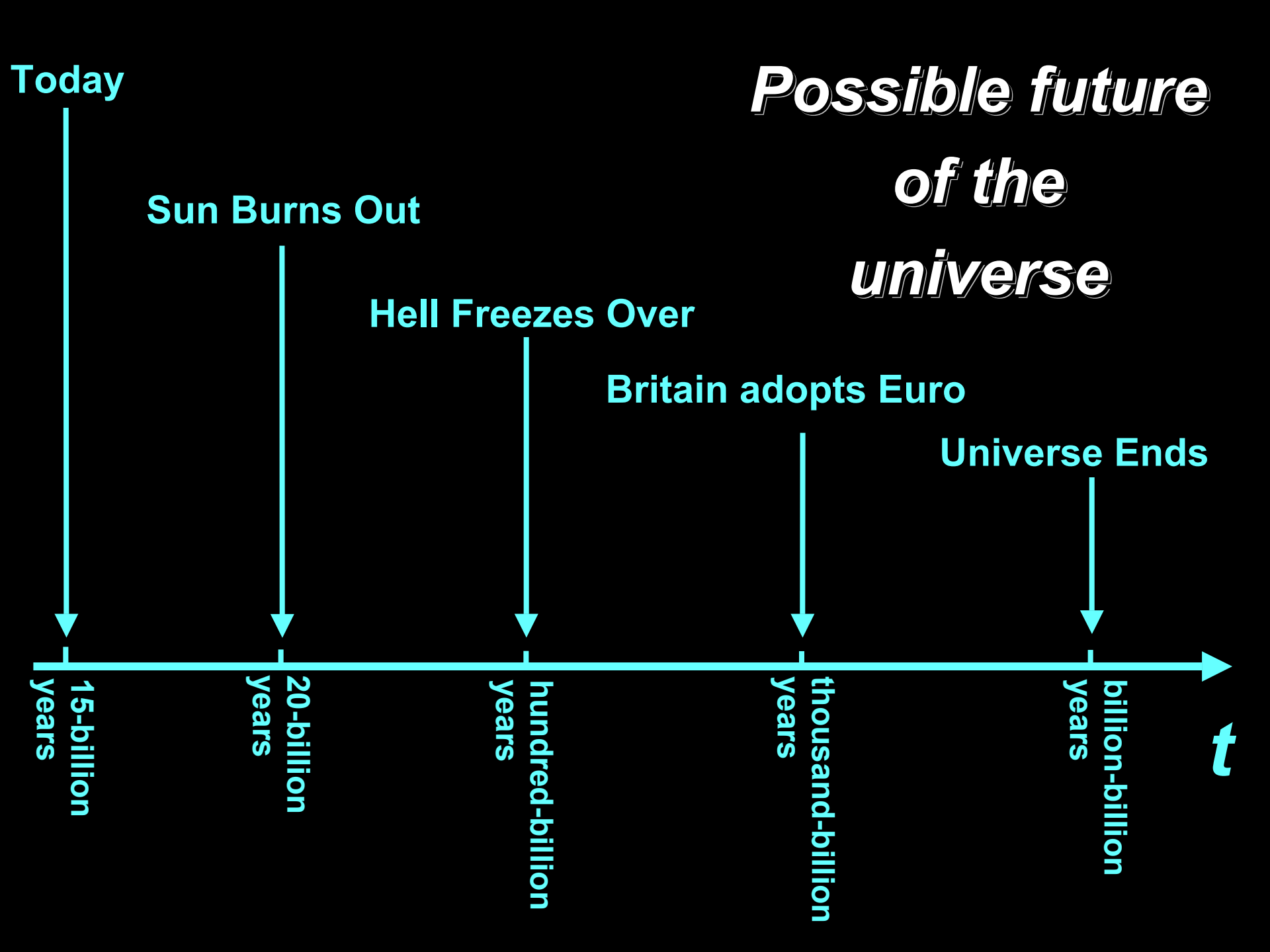


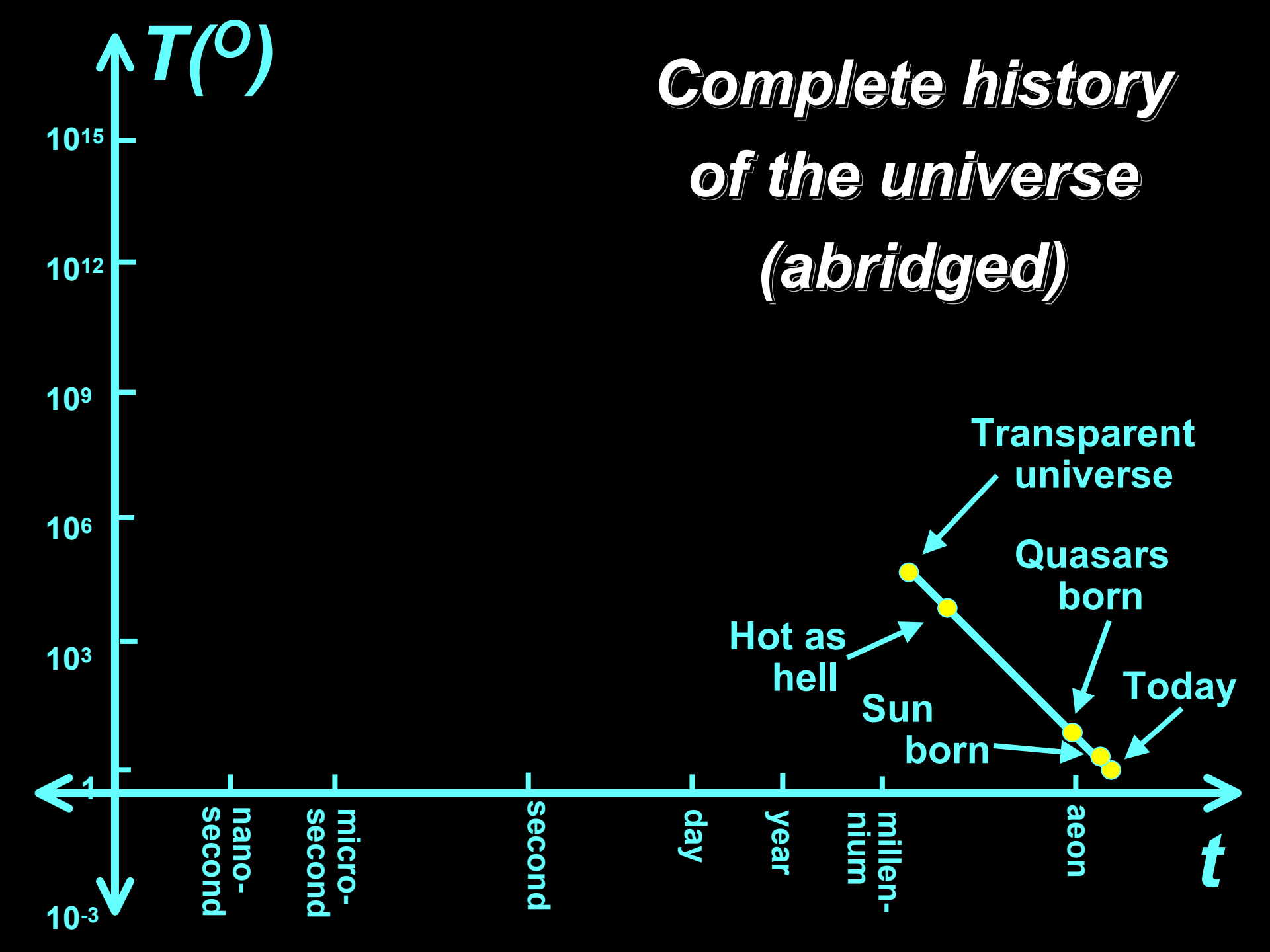
T = 3K = –270 C

Cosmic background radiation

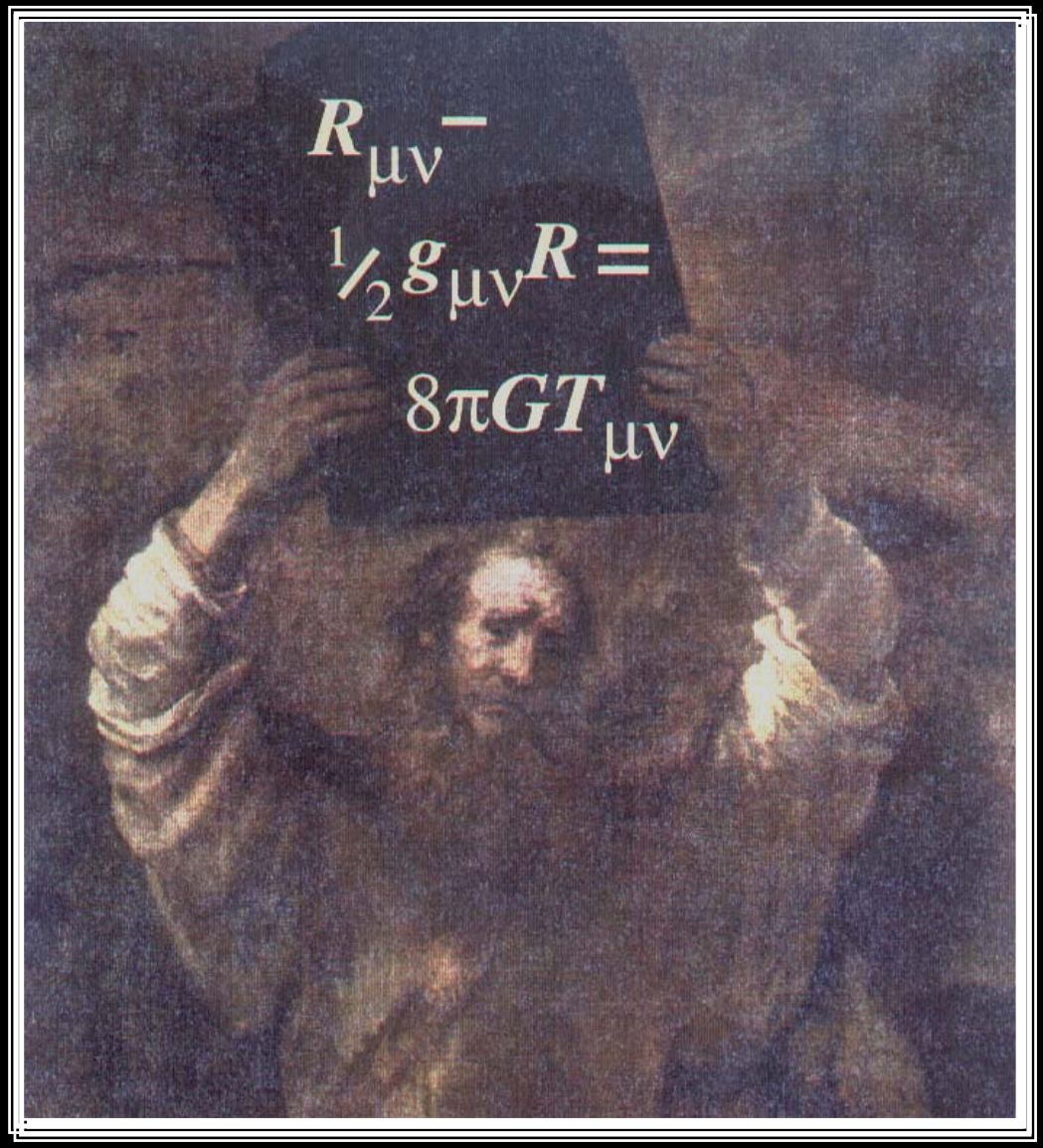
looking out in space is looking back in time




Possible future of the universe
Today
Sun Burns Out
Hell Freezes Over
Britain adopts Euro
Universe Ends
15-billion years
20-billion years
hundred-billion years
thousand-billion years
billion-billion years
t


T(°)
Complete history of the universe (abridged)
10^15
10^12
10^9
10^6
10^3
1
10^-3
Transparent universe
Quasars born
Hot as hell
Today
Sun born
nano-second
micro-second
second
day
year
millen-nium
aeon
t

Modern laws of Genesis



(10 nonlinear partial differential equations)

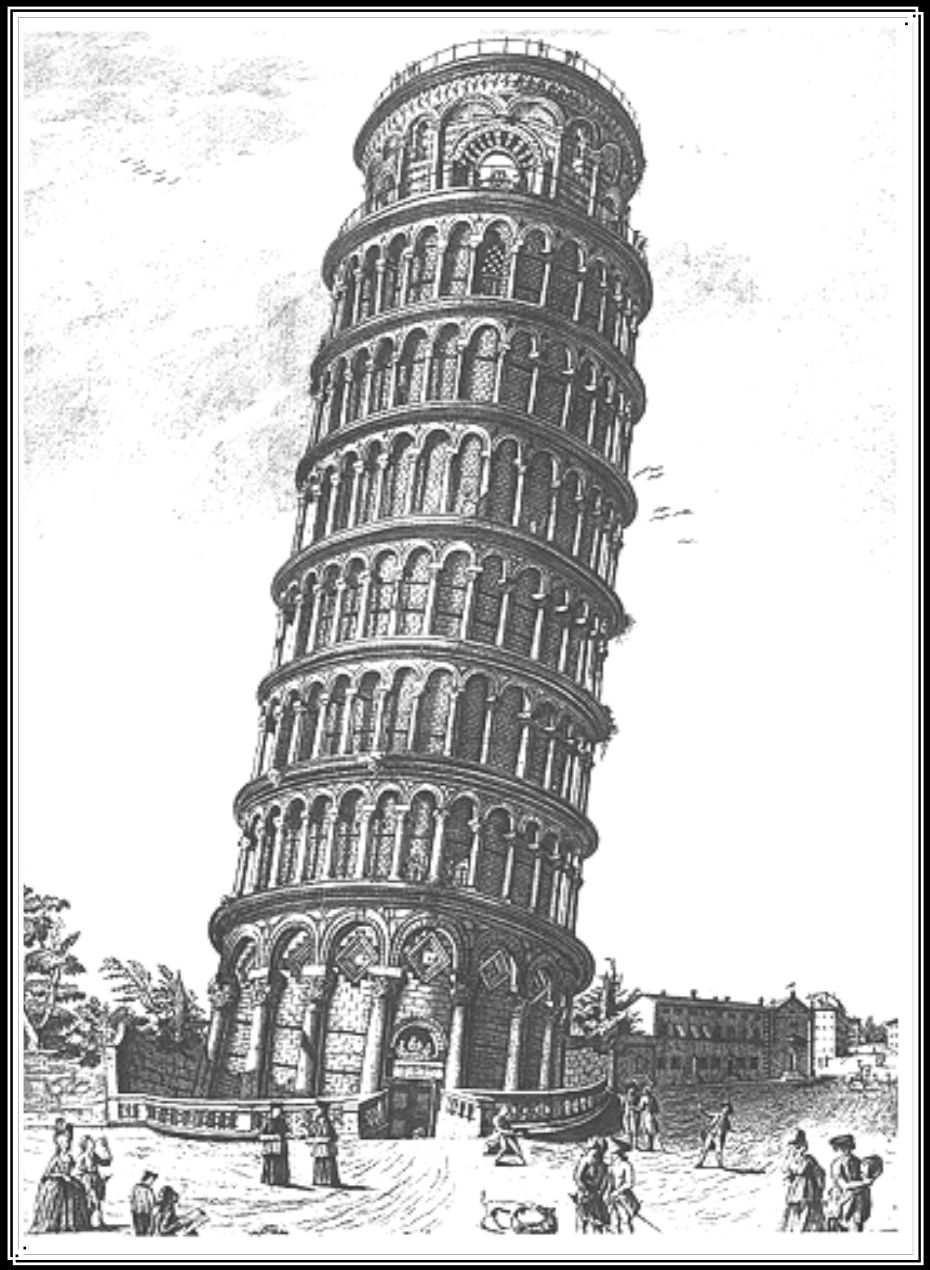
Particle Accelerators

CERN (Geneva)

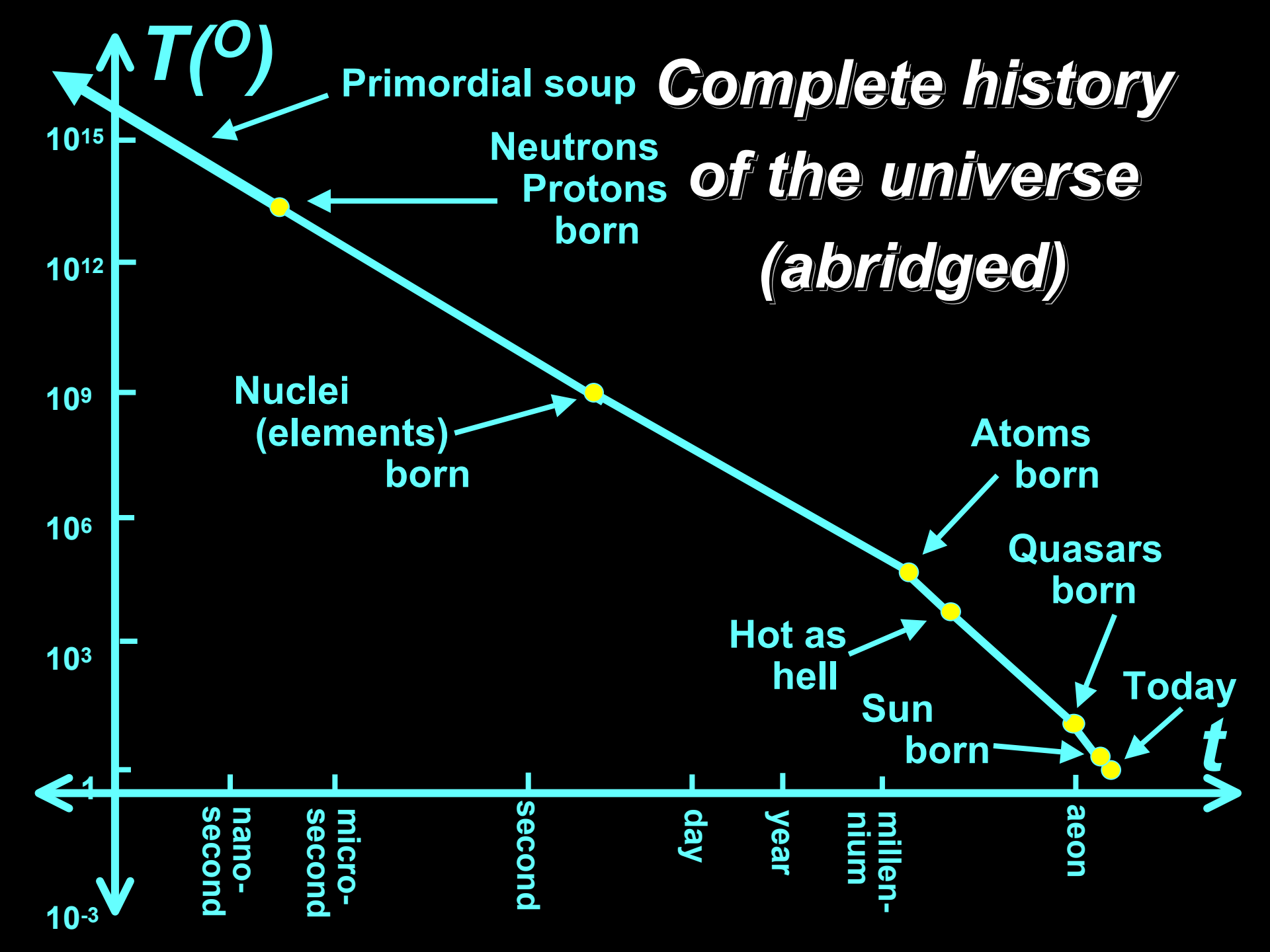
Fermilab (Batavia)

Particle Accelerator = Time Machine = Telescope

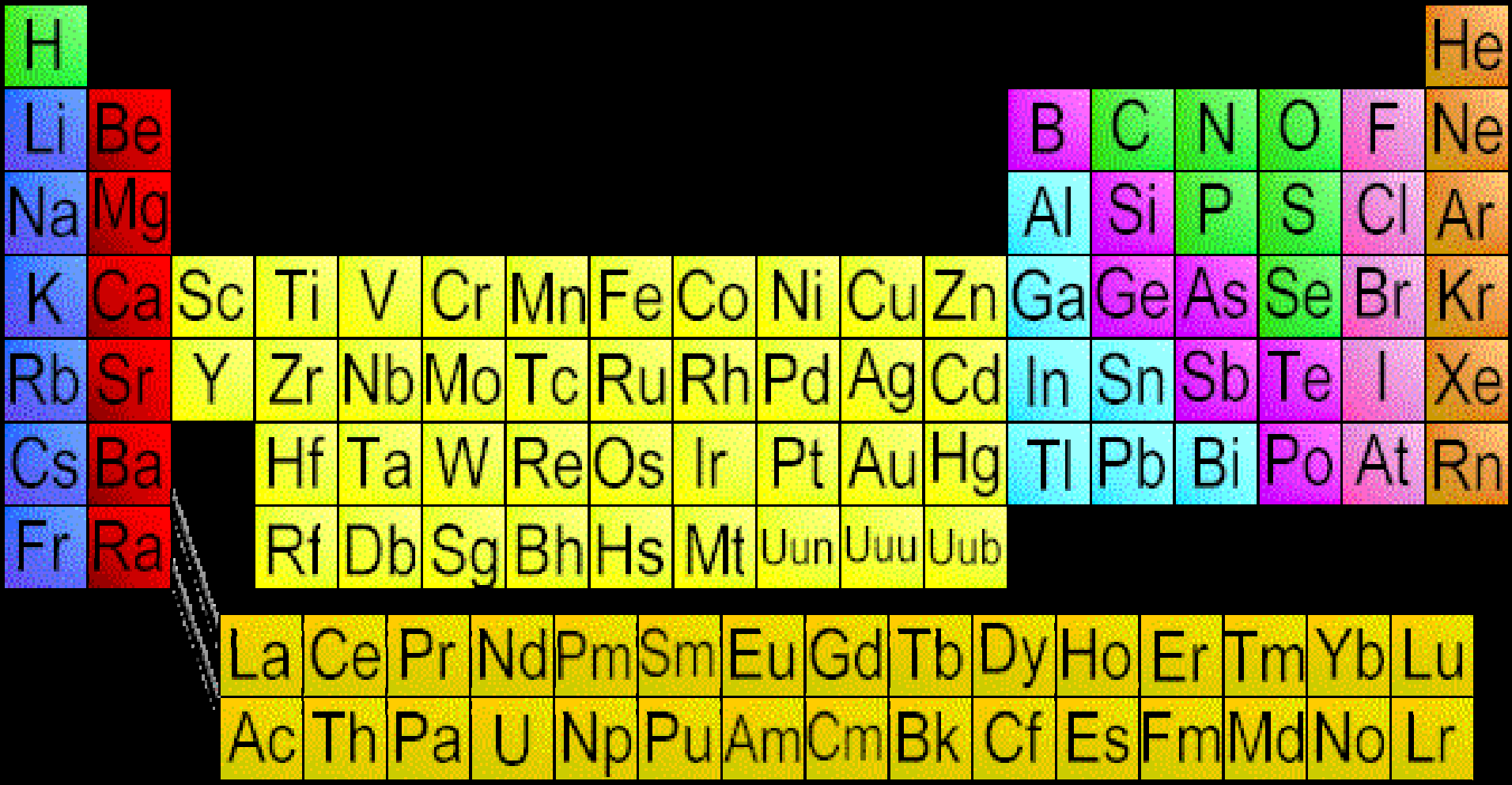
Galileo's accelerator



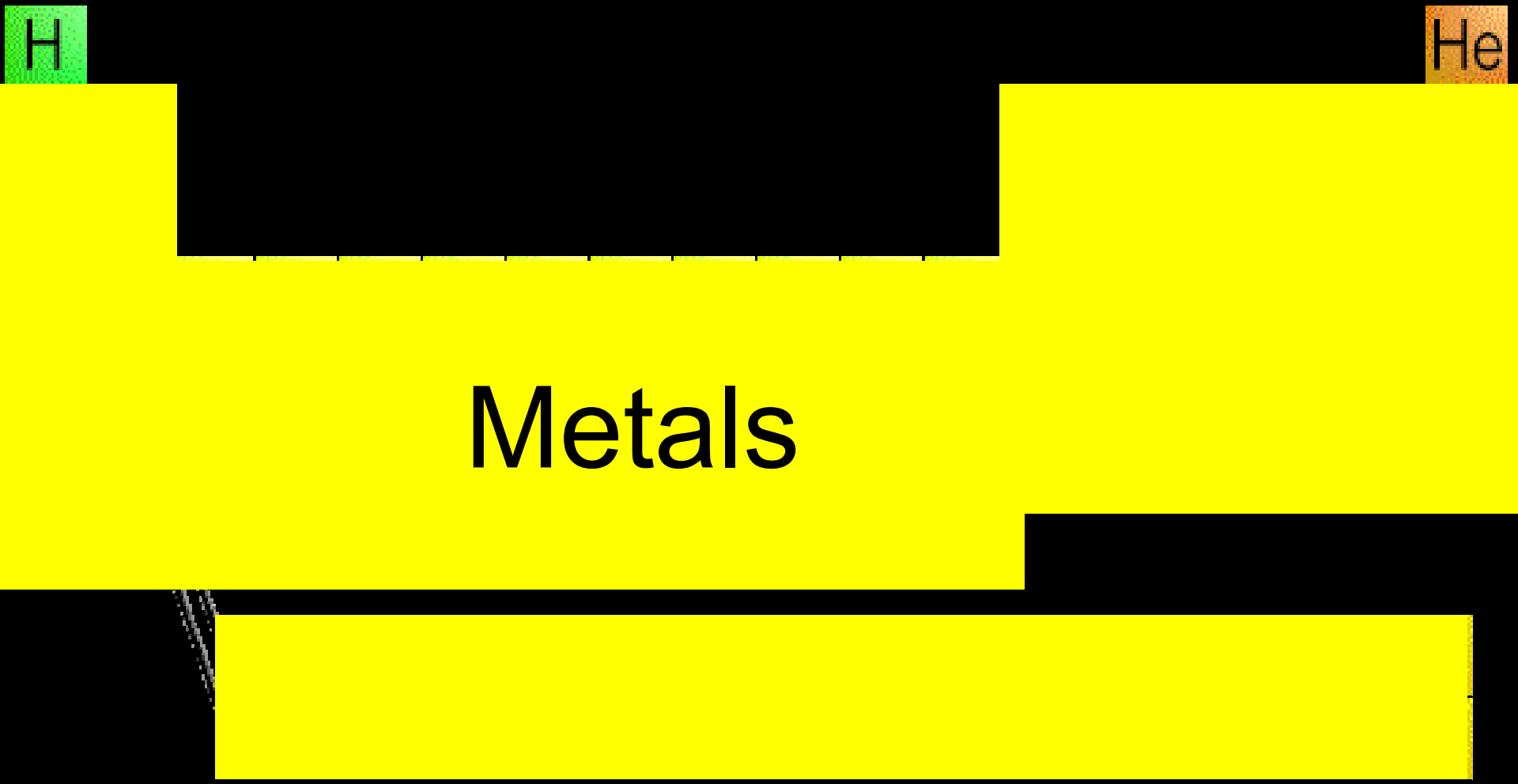

Fermilabs
Primordial
SOUP


T(°)
Primordial soup
Complete history
of the universe
(abridged)
Neutrons
Protons
born
10^15
10^12
10^9
10^6
10^3
1
10^-3
Nuclei
(elements)
born
Atoms
born
Quasars
born
Hot as
hell
Sun
born
Today
t
nano-
second
micro-
second
second
day
year
millen-
nium
aeon

Periodic table - chemist



Periodic table - cosmologist



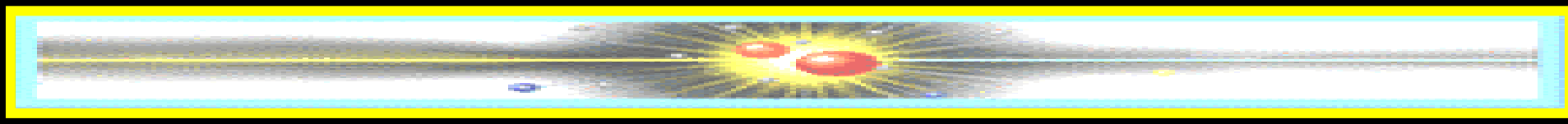
The Universe today:

73% Hydrogen (10^{-5} ^{2}H-deuterium)
26% Helium (10^{-5} ^{3}He)
1% Metals

The Universe 3 minutes AB:

76% Hydrogen (10^{-5} ^{2}H- deuterium)
24% Helium (10^{-5} ^{3}He)
10^{-8}% Lithium

Primordial soup



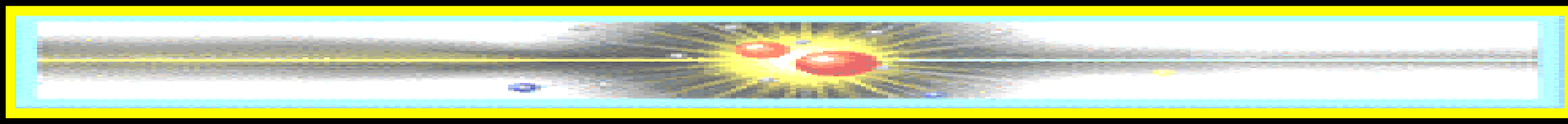
$3X10^{15}$ degrees

3,000,000,000,000,000°

$4X10^{-12}$ seconds AB

0.000 000 000 004 seconds AB

Primordial soup



Caution !!!

CONDENSED

50 Earth masses in matter
50 Earth masses in antimatter
\+ extra mountain of matter

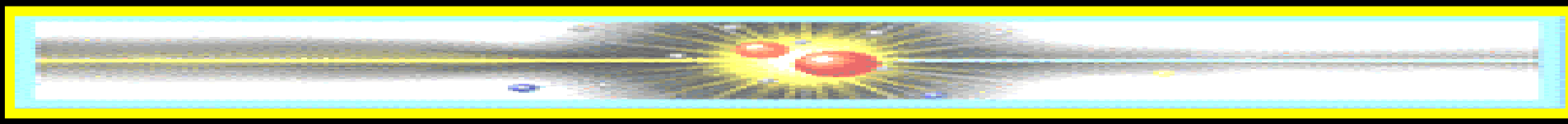
HOT

64 billion years of energy output of sun

CONTENTS

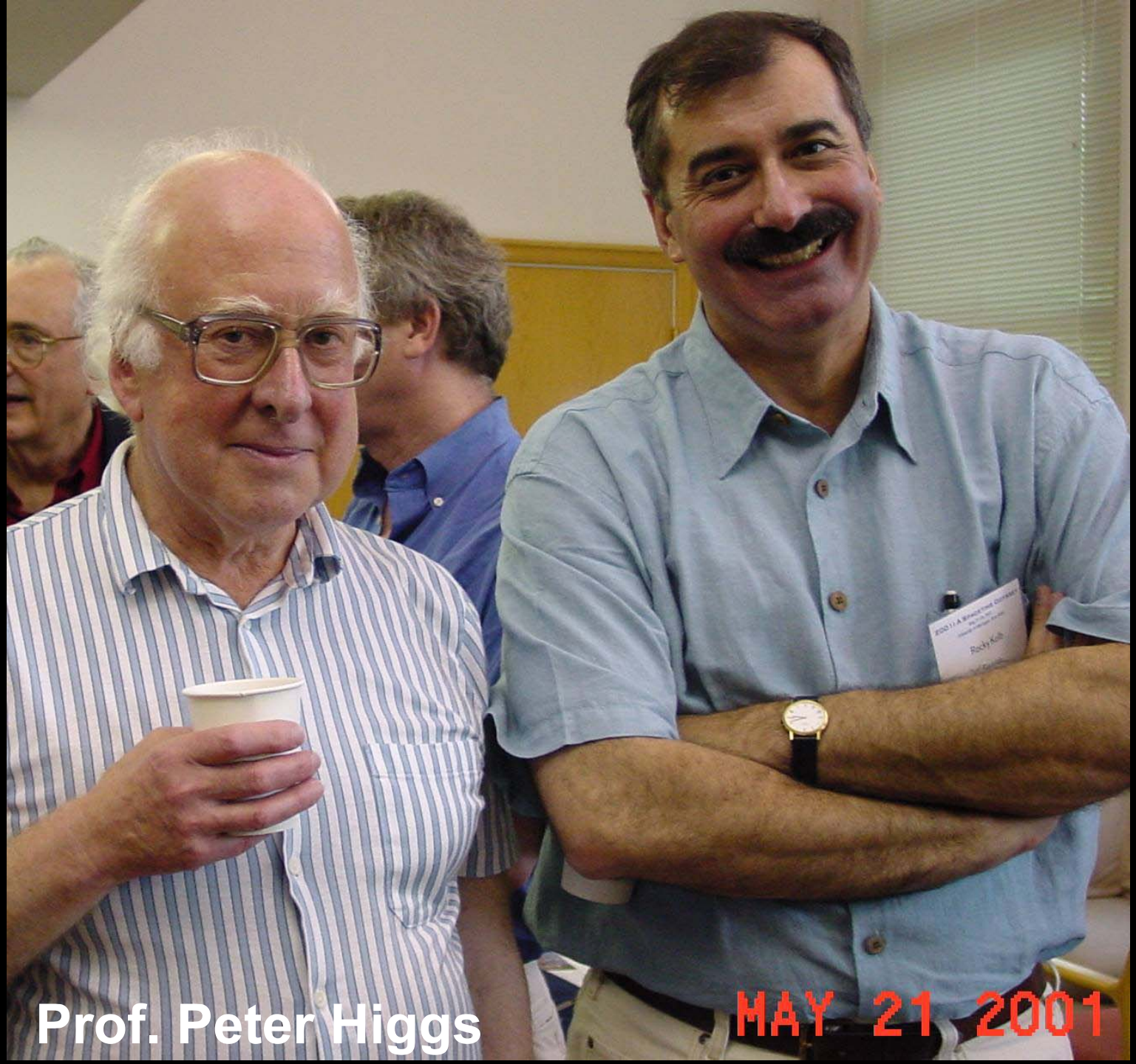
elementary particles and antiparticles

Primordial soup



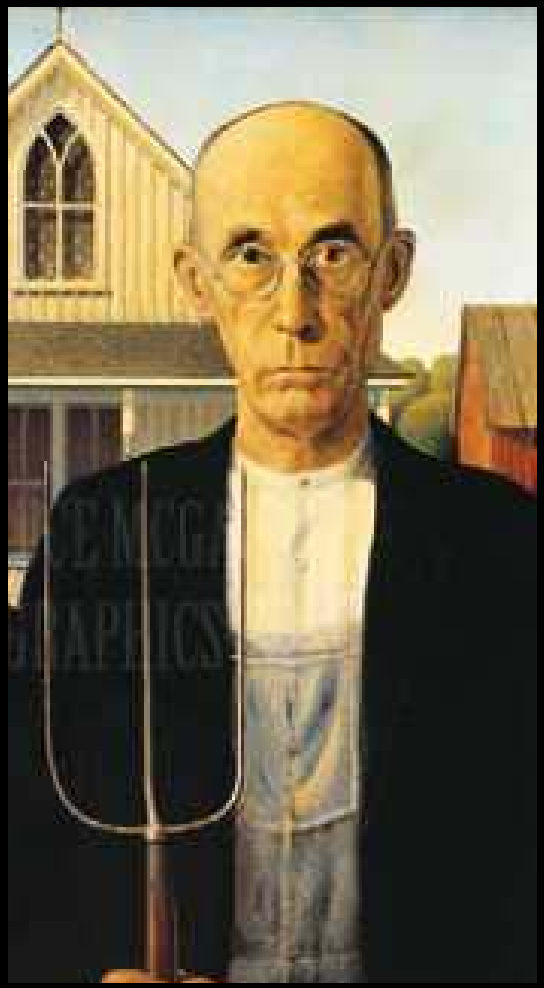
KNOWN INGREDIENTS:

56% QUARKS
16% GLUONS (STRONG FORCE)
9% ELECTRON-LIKE PARTICLES
9% W's AND Z's (WEAK FORCE)
5% NEUTRINOS
2% PHOTONS (ELECTROMAGNETIC FORCE)
2% GRAVITONS (GRAVITATIONAL FORCE ?)
1% HIGGS BOSONS (???)


Prof. Peter Higgs
MAY 21 2001

Will Higgs be found in

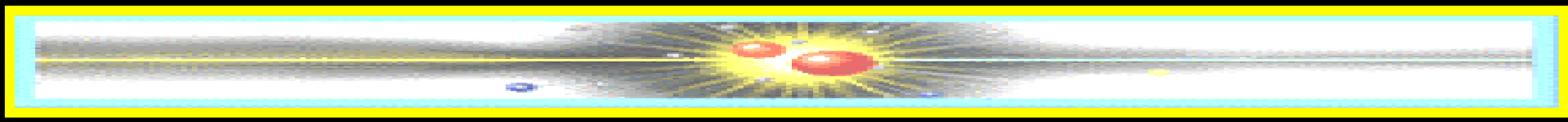
USA (Fermilab)? **or** **Europe (CERN)?**



Mike Witherell
Director

Luciano Maiani
Director General

Primordial soup



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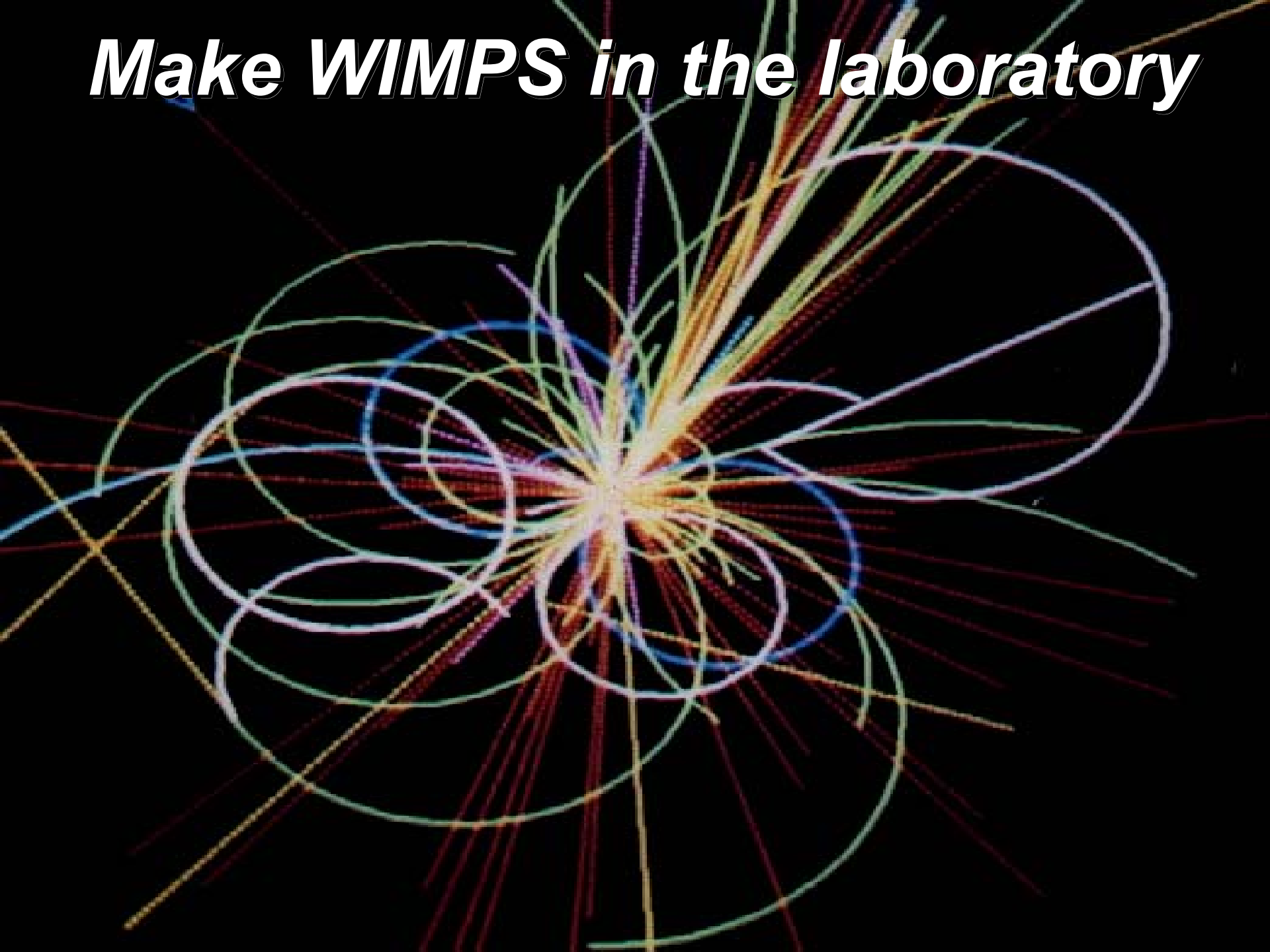
5% NEUTRINOS
2% PHOTONS (ELECTROMAGNETIC FORCE)
2% GRAVITONS (GRAVITATIONAL FORCE)
1% HIGGS BOSONS (???)

SECRET INGREDIENT:

DARK MATTER (WIMP!)

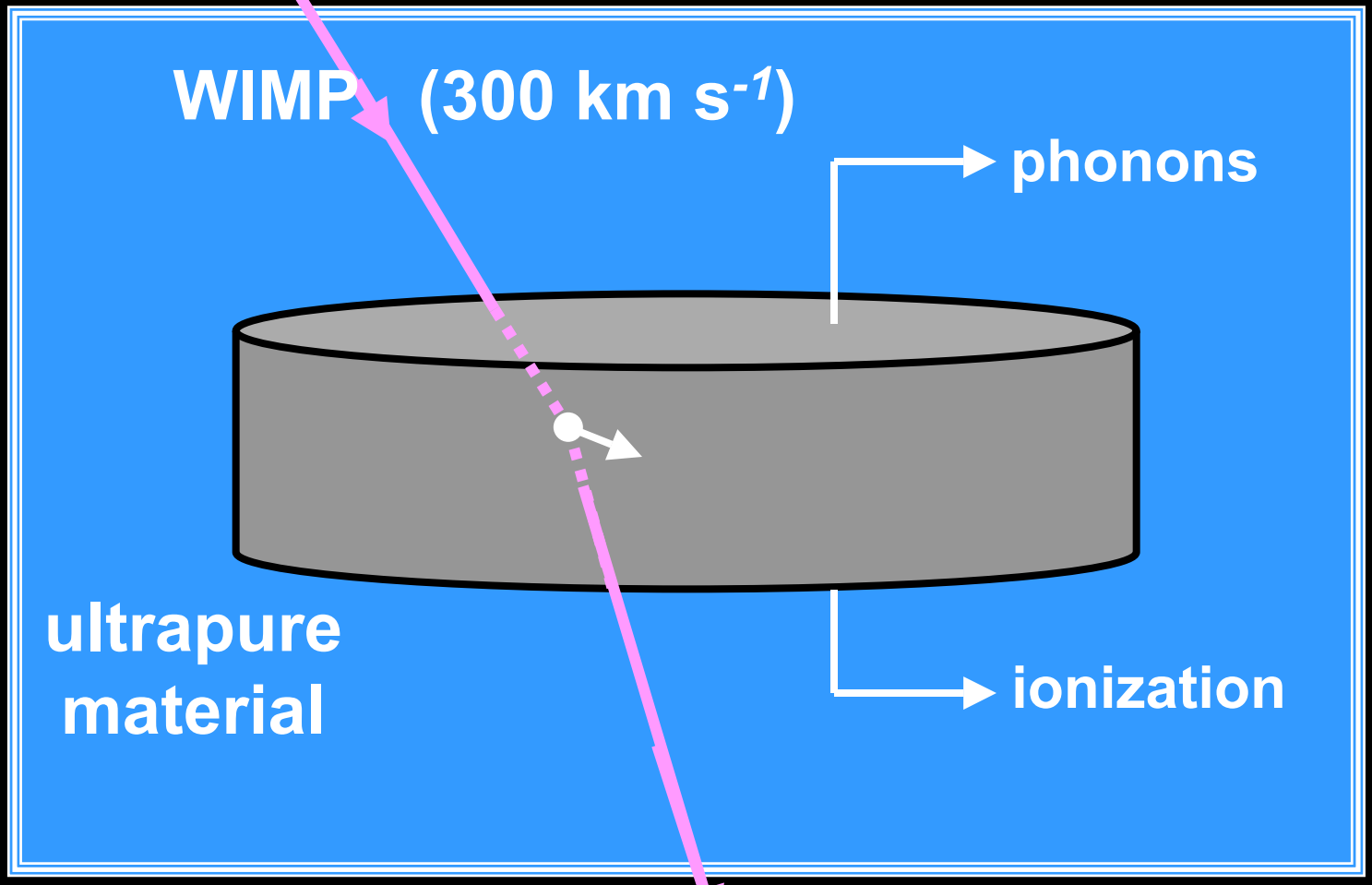
Make WIMPS in the laboratory



Detect relic WIMPS

Cleveland Potash Ltd. at Boulby in Yorkshire

Detect relic WIMPS



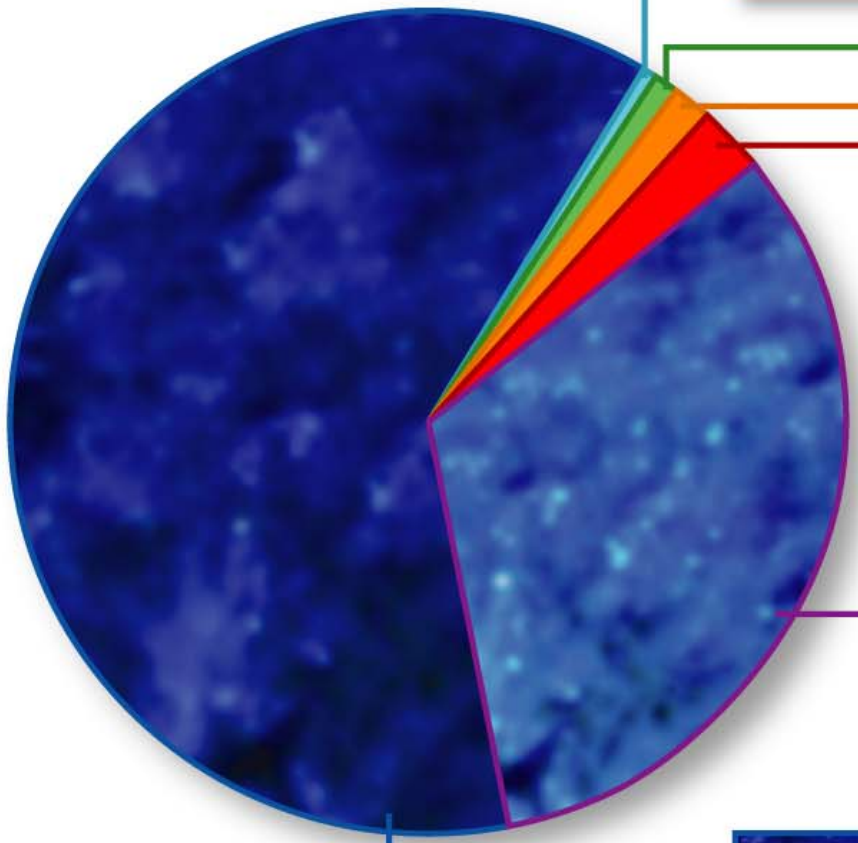
Every cubic inch of space is a

MIRACLE !

- Walt Whitman

- background radiation
- virtual particles
- Higgs potential
- dark matter
- dark energy

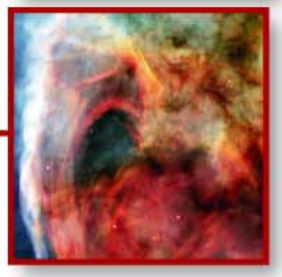
Cosmic Pie



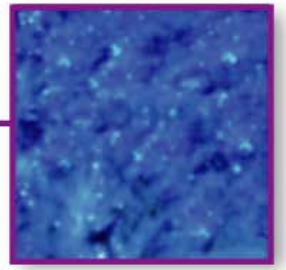
Heavy Elements:
0.03%

Neutrinos:
0.47%

Stars:
0.5%



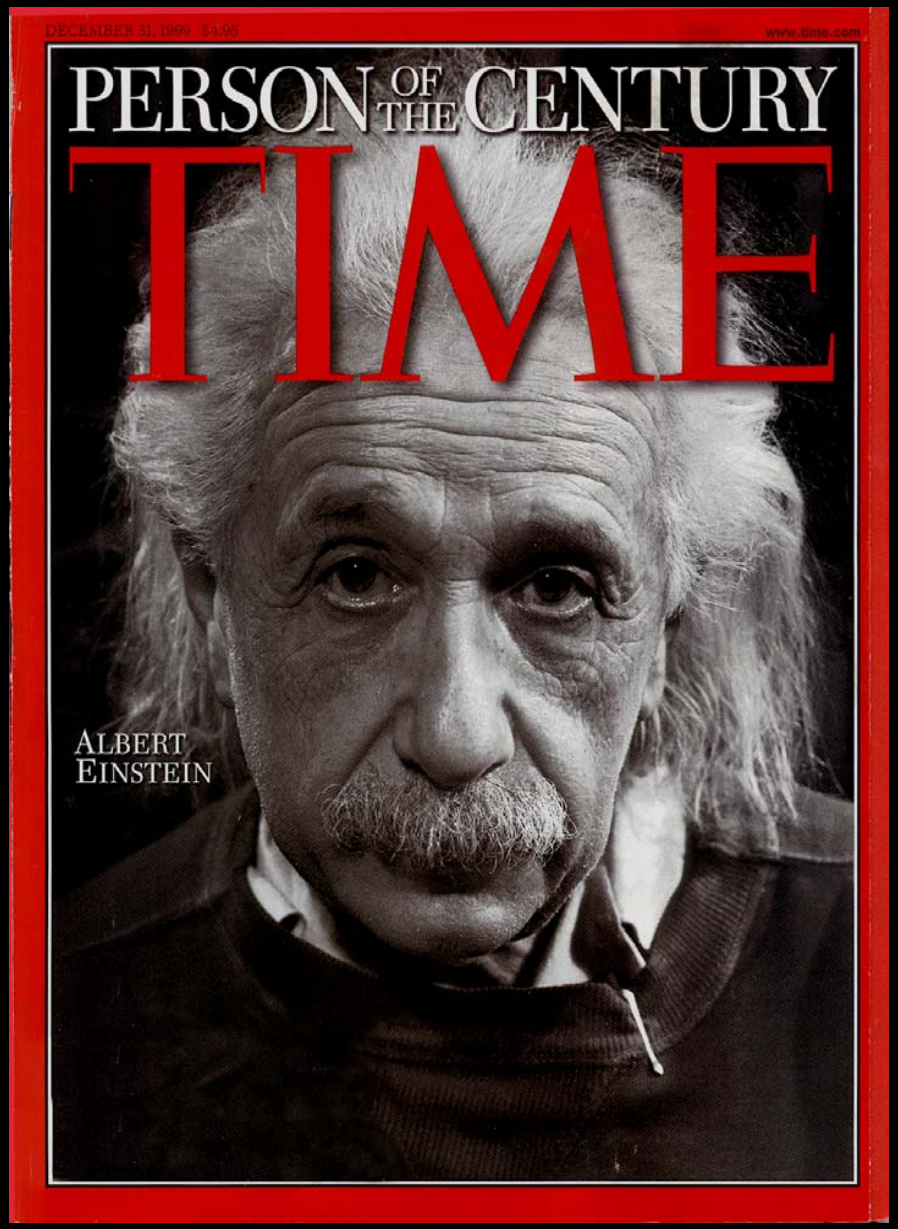
Free Hydrogen
and Helium:
4%



Dark Matter:
25%

Dark Energy:
70%

95% mystery

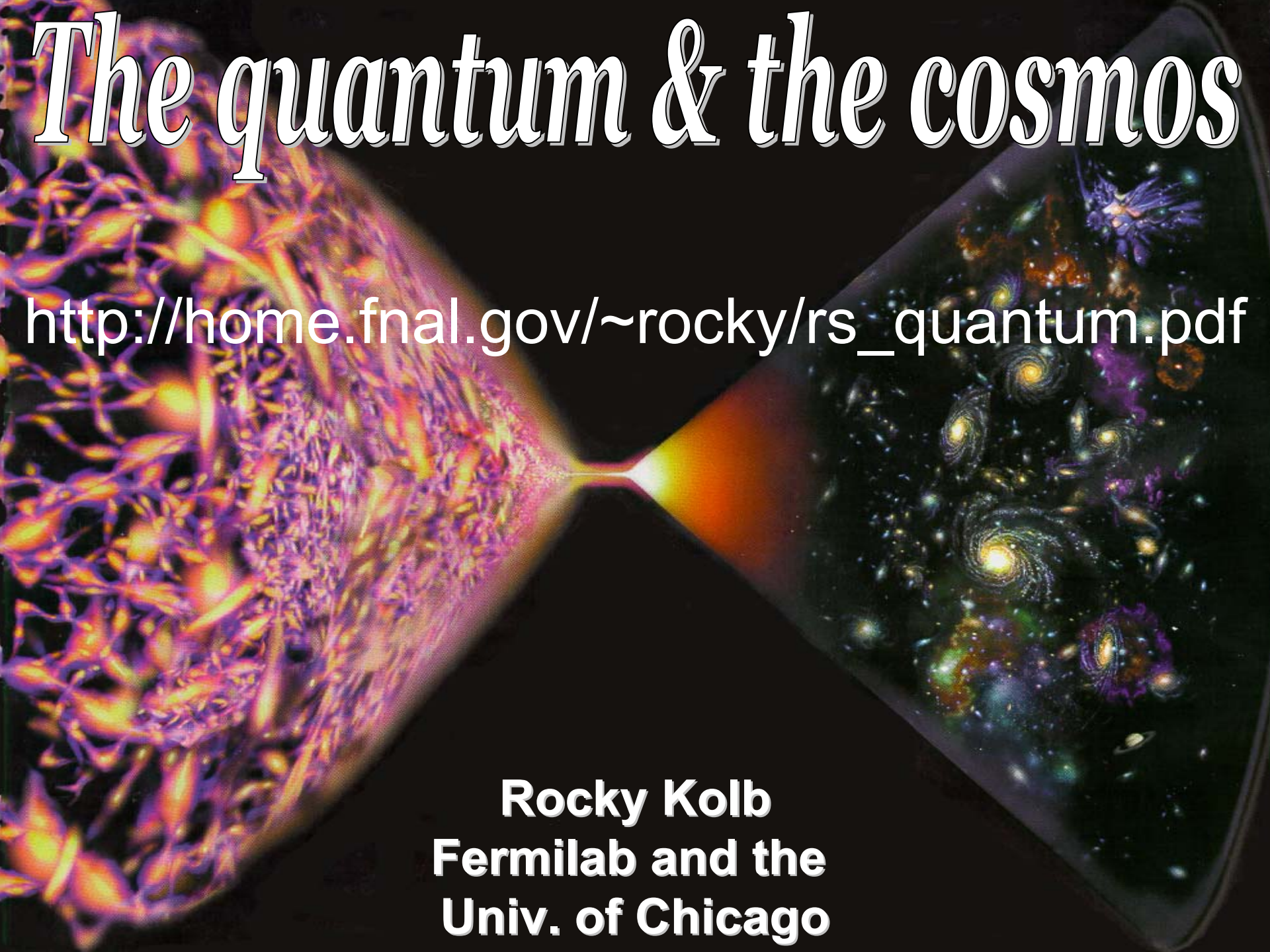

DECEMBER 31, 1999 $4.95
www.time.com
PERSON OF THE CENTURY
TIME
ALBERT EINSTEIN


DECEMBER 31, 2099 $24.95
www.time.com
PERSON OF THE NEXT CENTURY
TIME
?


human curiosity

The quantum & the cosmos

http://home.fnal.gov/~rocky/rs_quantum.pdf



Rocky Kolb
Fermilab and the
Univ. of Chicago